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**THE OCCURRENCE OF OIL AND GAS IN DEVONIAN SHALES
AND EQUIVALENTS IN WEST VIRGINIA**

By
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West Virginia Geological and Economic Survey
Morgantown, West Virginia

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Final Report

by

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1. INTRODUCTION

Between January 1977 and June 1980, stratigraphic and paleontologic studies of Devonian rocks were performed by personnel of the West Virginia Geological and Economic Survey, and graduate students at West Virginia University. These studies were part of the Eastern Gas Shales Project that was funded by the United States Department of Energy. Major products of these studies are dissertations by D.W. Neal (1979) and M.E. Dowse (1980); theses by S.L. Duffield (1978) and G.R. Clarkson (1980); papers presented at professional meetings (Schwietering, 1978, 1980; Neal and Patchen 1979; Dowse, 1979); and a state-wide network of cross sections by Neal, Dowse, and Schwietering. The cross sections are waiting publication by the U.S. Geological Survey. In addition, maps and cross sections showing the thickness and correlation of Middle and Upper Devonian rocks in West Virginia were supplied to the U.S. Geological Survey in Reston, Virginia for their regional stratigraphic study of Middle and Upper Devonian rocks in the Appalachian basin.

This report contains a summary of these stratigraphic and paleontologic studies; a model of sedimentation to explain the origin and distribution of the Devonian shales and their equivalents; a discussion of the origin and occurrence of oil and gas in these Devonian rocks; and a section suggesting areas for exploration for oil and gas in Upper Devonian rocks in West Virginia.

The author wishes to thank Douglas G. Patchen for his comments on preliminary versions of this report.

2. STRATIGRAPHY

Before discussing the stratigraphic interpretations of the information shown on the maps in this report, some comments about the source and nature of the data used in constructing the maps are in order.

There is a high level of confidence in the identification of the Middle Devonian Hamilton Group and Tully Limestone on gamma-ray logs in north-central West Virginia. However, where the Tully Limestone is absent in the western and southern parts of the State it is difficult to separate the Hamilton Group from overlying rocks, thus, there is only a moderate to low level of confidence in the thicknesses of the Hamilton Group, the Genesee Formation, and the Sonyea Formation shown on Plates 6, 7, 9, 10, 11, and 12 in western and southern West Virginia.

The level of confidence in the recognition of Upper Devonian formations on gamma-ray logs is highest in the western part of the State where highly radioactive shales are present. It is low to very low in the central and eastern parts of the State where highly-radioactive shales are few in number or absent.

The thickness of highly-radioactive shales mapped on Plates 7, 10, 12, 14, 16, and 18 are thought to be approximations of the thickness of very dark-gray to black organic-rich shales. This correlation between high radioactivity and dark organic-rich shales was determined by comparing sample-descriptions and gamma-ray logs from the same wells or nearby wells. This correlation is most applicable in the southwestern part of the State.

The thickness of highly-radioactive shale shown on the plates listed above was determined by a technique proposed by Harper and Piotrowski (1978). In this technique, a shale base line is established on a gamma-ray log by drawing a line through the average value for gray shales. Then a line 20 API units

higher than the base line is drawn on the log. Shales with gamma-ray values higher than this second line are considered to be highly radioactive. This technique is subject to error because of variations in the quality of logs, calibration of instruments, hole conditions, and interpreter's judgment. For these reasons, the thickness values of highly-radioactive shale shown on Plates 7, 10, 12, 14, 16, and 18 should be considered as approximations. Even though these maps only show approximate thicknesses of highly-radioactive shale, and by implication organic-rich shale, they can be useful in locating areas in which to do the detailed studies necessary to locate drilling prospects for gas and oil from organic-rich shales.

Harper and Piotrowski (1978) also suggest a technique to measure the amount of "clean" sandstone and siltstone in a well. As before, a shale base line is drawn on the log. Another line is drawn through the lowest gamma-ray readings in a sandstone-shale sequence. This second line is the 100% sandstone base line. A third line is drawn halfway between the shale base line and the 100% sandstone base line. This third line represents the boundary between "clean" sandstone and siltstones and sandy or silty shales. This technique is subject to the same types of error as the technique to identify highly radioactive shales. The presence of "clean" sandstone or siltstone indicates the presence of rocks coarser grained than the rocks making up the shales in western West Virginia. Therefore, the maps showing the distribution of highly radioactive shale and "clean" sandstone and siltstone show in a general way the distribution of an organic-rich shale facies and a coarser grained facies. In essence they are crude facies maps.

Middle and Upper Devonian formations recognized in New York and Ohio have been traced into western and central West Virginia by using gamma-ray logs and examining well cuttings (Schwietering, 1970, 1979; Wallace and others, 1978a, 1978b; Roen and others, 1978; West, 1978; Neal, 1979; Dowse, 1980). The

names of these formations are shown on Figure 1. Plates 3 through 18 are maps showing the distribution, thickness, and facies of these Middle and Upper Devonian formations. These plates will be discussed in order.

Plate 3 shows the formations in contact across the Middle and Upper Devonian boundary. Where the Genesee Formation rests on the Hamilton Group in the eastern panhandle and on the Tully Limestone in north-central West Virginia, the contact between Middle and Upper Devonian rocks appears to be conformable. Apparently there was continuous deposition during the passage from Middle to Late Devonian time in this area. West and south of the occurrence of the Tully Limestone an unconformity, or possibly a diastem, separates Middle Devonian from Upper Devonian rocks. If a diastem is present, it is located in a narrow band parallel to the western and southern occurrence of the Tully. Such a diastem would be similar to the one separating Middle Devonian and Upper Devonian rocks west of the occurrence of the Tully Limestone in western New York (Heckel, 1972, pages 265-268).

Going west from central West Virginia into Ohio and eastern Kentucky, and south into southwestern Virginia, progressively younger rocks lie on progressively older rocks across the Middle and Upper Devonian boundary (Plate 3). This relation is evidence for an onlap of Upper Devonian rocks onto an erosion surface cut across Middle Devonian rocks. Farther west and southwest in central and western Ohio, central Kentucky, and central Tennessee, Upper Devonian rocks rest on rocks that are Ordovician to Middle Devonian in age (Conant and Swanson, 1961).

Plates 4 and 5 show the thickness of the Devonian shales in West Virginia. The Devonian shales overlie the Onondaga Limestone, the Huntersville Chert, or the Needmore Shale, and underlie the Mississippian Bedfore Shale or its equivalents. On these maps, the thickness of the relatively thin (at most about 200 feet thick) Bedford Shale is included with the thickness of the

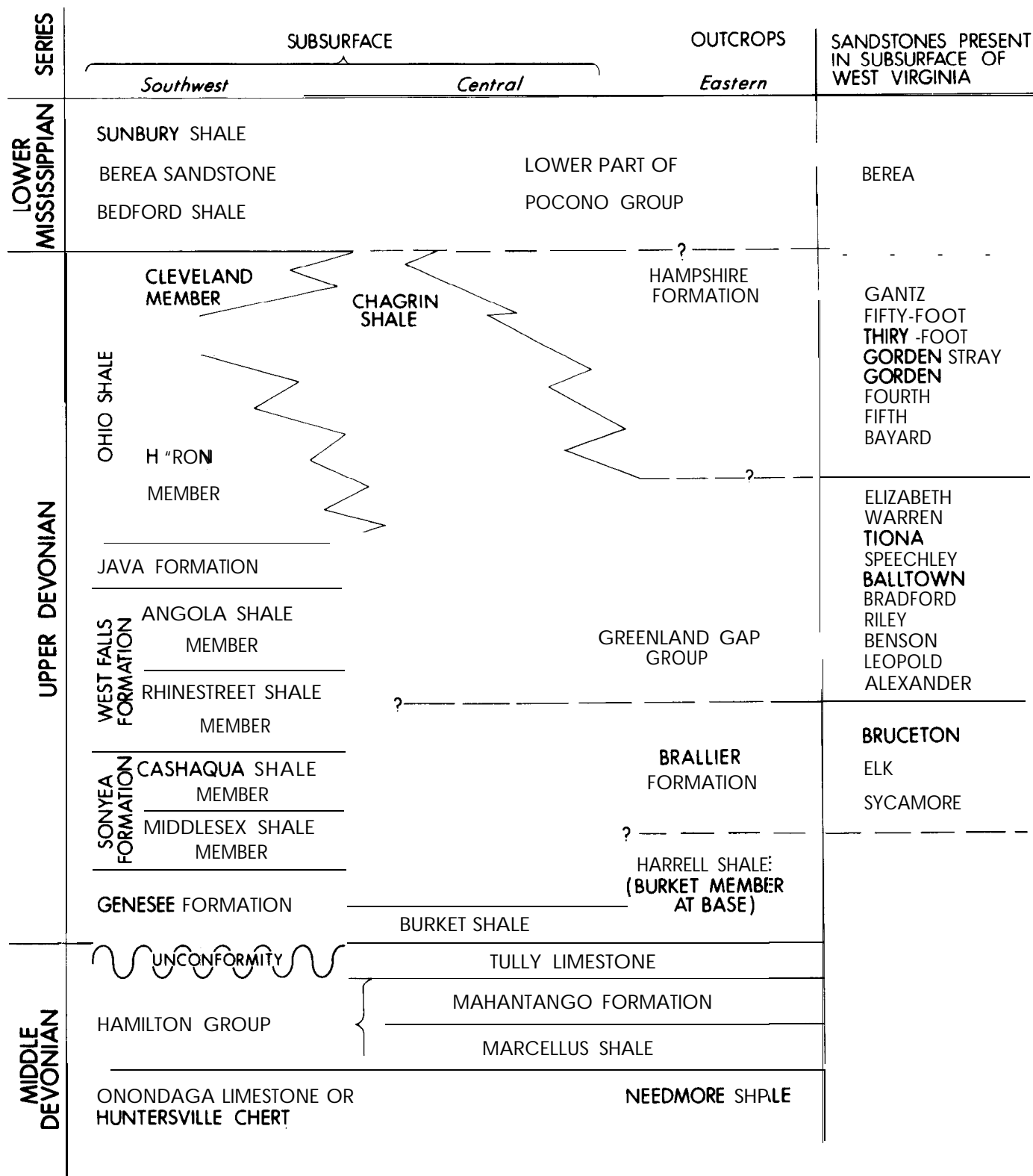


Figure 1. Tentative correlation of Middle and Upper Devonian formations in West Virginia.

Devonian rocks because on gamma-ray logs a boundary between Devonian and Mississippian rocks cannot be consistently identified. The inclusion of the Bedford with the Devonian rocks does not alter conclusions derived from the maps. Both maps show Devonian rocks thickening from less than 1000 feet in the westernmost part of West Virginia to more than 6000 feet in the eastern part of the State. The rocks thicken toward the primary source of sediments for the Catskill clastic wedge. West of West Virginia, equivalents of these rocks thin to about 190 feet on the crest of the Cincinnati Arch in west-central Ohio (Moses, 1922; Schopf and Schwietering, 1970), and between 20 and 35 feet on the crest of the Nashville Dome in central Tennessee (Conant and Swanson, 1961; Provo, 1977). The Cincinnati Arch and the Nashville Dome form the western boundary of the Appalachian basin.

In West Virginia, the Middle Devonian Series consists of the Onondaga Limestone, Huntersville Chert, Needmore Shale, Hamilton Group, and the Tully Limestone (Figure 1). The Onondaga, Huntersville, and Needmore are facies of each other and make up the lower part of the Middle Devonian Series. These rocks underlie the "Devonian Shales" and will not be described in this report. Except in the southwestern part of the State, the Onondaga Limestone and its equivalents are overlain by the Hamilton Group. In the southwestern part of the State, the Onondaga is overlain by Upper Devonian rocks. The Tully Limestone rests on the Hamilton Group in north-central and east-central West Virginia, but elsewhere in the State the Hamilton Group is overlain by Upper Devonian rocks (Plate 3). The Hamilton Group and the Tully Limestone will be described together in this report.

In West Virginia, the Hamilton Group is thickest in the eastern panhandle where it is as much as 1600 feet thick (Woodward, 1943, page 310). It thins west and south of the panhandle and is absent in southwestern West Virginia (Plate 6). The Hamilton Group is divided into two formations: the Marcellus

Shale at the base, and the Mahantango Formation at the top. The Marcellus Shale consists of highly radioactive organic-rich black shale with a medial zone of interbedded calcareous shales and thin limestones that are moderately radioactive in the northeastern part of the State. This medial zone has been informally named the Purcell Member. In contrast to the highly-radioactive Marcellus Shale, in the subsurface of West Virginia, the Mahantango Formation is very dark-gray shale that is only moderately radioactive. Thus the highly-radioactive shale mapped on Plate 7 shows the thickness and distribution of the Marcellus Shale. Furthermore, the siltstones present in the Mahantango in south-central Pennsylvania, western Maryland, and the eastern panhandle of West Virginia (Dennison and Naegle, 1963; Ellison, 1965; Hasson and Dennison, 1978) are not present in the formation in north-central West Virginia. Gas is produced from the Marcellus Shale in Gilmer County.

The Tully Limestone is exposed at several places along the Allegheny Front (Hasson and Dennison, 1978). Dennison has found exposures of the Tully Limestone in the center of the Elkins Anticline north of Elkins (personal communication). Apparently this is the limestone identified as the Landes Limestone by Reger (1931, page 391). The Tully Limestone exposed at Petersburg in Grant County and a few miles north of Elkins in Randolph County contains late Middle Devonian (Middle Varcus Subzone) conodonts (A. Harris, written communication, 1979).

Although the Tully Limestone typically is composed of dark-gray argillaceous limestone, Ellison (1965), Heckel (1969, 1973), and Hasson and Dennison (1978) report that the Tully passes eastward into calcareous shale in south-central Pennsylvania, western Maryland, and the eastern panhandle of West Virginia. In West Virginia, the thickness of the Tully Limestone ranges from 0 to more than 75 feet (Plate 80). It is thickest along the axis of the Chestnut Ridge Anticline. It may be that the Tully is anomalously thick along

the axis of the anticline because of flowage of material to the crest of the anticline, or the cumulative effect of many small antithetic faults.

Cross sections by Schwietering and others (1978) suggest that the Tully Limestone rests conformably on the Hamilton Group. These cross sections, and Plate 6, show the Hamilton thinning to the west and southwest of the eastern panhandle. The westward thinning of the Hamilton, the pinching out of the Tully to the west and south of north-central West Virginia, and the unconformity and possible diastem between Middle and Upper Devonian rocks in the southwestern part of the state, together suggest that in West Virginia, the Hamilton and the Tully were deposited in shallow water along the western margins of an epicontinental sea.

West of the Allegheny Front, the thickness of the Genesee Formation ranges from 0 to more than 300 feet (Plate 9). The Genesee Formation west of the front is equivalent to the lower part of the Harrell Shale (Figure 1). A highly-radioactive shale at the base of the Genesee Formation is a subsurface equivalent of the black Burket Member of the Harrell Shale. Thus the Genesee and the Harrell consist of a basal organic-rich black shale that is overlain by very dark-gray shale with a few beds of dark-gray siltstone less than 6 inches thick.

Highly radioactive shale in the Genesee Formation ranges from 0 to more than 50 feet thick (Plate 10). An elongated pod of thick highly radioactive shale with a long axis oriented NE-SW is located in Gilmer, western Braxton, southeastern Calhoun, Clay, eastern Kanawha, and western parts of Nicholas and Fayette Counties. Gas is produced from this pod of highly radioactive shale in Gilmer County. Other parts of this pod of highly radioactive shale may be reservoirs of natural gas. However, because the pod is relatively thin (50 feet or less) and deep (6000 to 8000 feet), it is not a primary target for gas

exploration, but a zone to be tested along with deeper zones. No "clean" sandstones or siltstones were recognized on gamma-ray logs through this formation.

The Genessee Formation was deposited in a sea that transgressed west onto the craton. The sea did not cover that part of West Virginia west and south of the 0 thickness line on Plate 9 during the deposition of the Genessee. The absence of "clean" sandstones and siltstones in this formation suggests that the shoreline of the eastern source of sediments along the margin of the continent was far to the east of West Virginia.

The Sonyea Formation is equivalent to the upper part of the Harrell Shale and the lower part of the Brallier Formation (Figure 1). The base of the Sonyea is defined by a thin bed of highly radioactive shale called the Middlesex Member. In the western and central parts of the State, the top of the Sonyea Formation is defined by the base of the highly radioactive shale in the Rhinestreet Member of the overlying West Falls Formation. The top of the Sonyea Formation cannot be recognized in the eastern part of the State where the highly radioactive shale of the Rhinestreet Member is absent as a result of facies change.

The Sonyea Formation consists of gray, dark-gray, very dark-gray, and black shale. Siltstones of equivalent age are present in the eastern and central parts of the State (Plate 12). The upper part of the Harrell Shale and the lower part of the Brallier Formation consist of dark- to very dark-gray shale and beds of gray to dark-gray siltstone. The siltstone beds are thicker and more numerous in the Brallier Formation than they are in the underlying Harrell Shale. In parts of western West Virginia, the Sonyea Formation is included in the "Big White Slate" of the drillers.

The thickness of the Sonyea Formation ranges from 0 in the west to more than 400 feet in the central part of the State (Plate 11). Its thickness cannot be determined in the eastern part of the State, because there the Rhinestreet

Member is absent. The Sonyea is absent in western Wayne and southern McDowell Counties.

Highly radioactive shale in the Sonyea Formation is generally restricted to the Middlesex Member at the base of the formation. However, in the central part of the State, thin beds of highly radioactive shale are present throughout the formation. The total thickness of radioactive shale in the Sonyea ranges from 0 to more than 50 feet (Plate 12). The highly-radioactive shales in the Sonyea pinch out to the west against an unconformity (except in Mason County), and to the east they change facies into moderately radioactive shales. In Mason County, the highly-radioactive shales in the Sonyea change facies to the west into moderately radioactive shales. The relation of the "clean" sandstones and siltstones in units equivalent in age to the Sonyea in the eastern part of the State (Plate 12) with the Back Creek Siltstone exposed along the Allegheny Front and described by Avary (1978) and Avary and Dennison (1980) has not been established.

The transgression that began during the deposition of the Genesee Formation continued through the deposition of the Sonyea Formation. The sea covered all of the State except the western part of Wayne County and the southern part of McDowell County, areas where no Sonyea is present. Siltstones (turbidites) present in the eastern part of the State indicate an influx of coarser sediments from the east and progradation of the Catskill clastic wedge into the eastern part of the State.

The West Falls Formation is equivalent to the upper part of the Brallier Formation and the lower and possibly middle parts of the Greenland Gap Group ("Chemung Formation") (Figure 1). The formation can be recognized only in the western and central parts of the State (Plate 13) where the highly-radioactive organic-rich black shale Member at the base of the West Falls Formation and the basal highly-radioactive shale of the overlying Java Formation are

present. It cannot be recognized in the central and eastern parts of the State where these highly-radioactive shales pinch out into moderately radioactive shales and siltstones.

The West Falls Formation consists of greenish-gray, gray, dark-gray, very dark-gray, and black shales, and gray to dark-gray siltstones and sandstones. The siltstones and sandstones are thicker and more numerous in rocks of equivalent age in the eastern part of the State. Most of the highly-radioactive shale in the West Falls Formation is present in the Rhinestreet Member. The Rhinestreet Member was called the "Brown Shale Zone I" by Martin and Nuckols (1976), and considered part of the "Brown Shale" by Patchen and Larese (1976) and Bagnall and Ryan (1976). The Angola Shale is the upper member of the West Falls Formation. In western West Virginia, the Angola Shale is part of the "Big White Slate" of the drillers. The Brallier Formation has already been described. The lower part of the Greenland Gap Group (Scheer Formation) consists of gray to dark-gray siltstone and fine-grain sandstone, and gray to dark-gray shale. Dennison (1970) placed the boundary between the Greenland Gap Group and the Brallier Formation at the base of the lowest sandstone in the Upper Devonian Series along the Allegheny Front. The upper part of the Greenland Gap Group consists of red, green, and gray, fine- to coarse-grain sandstones that are thin- to very thick-bedded; conglomeratic sandstones; gray siltstones; gray to dark-gray shales; and red and green shales.

The thickness of the West Falls Formation ranges from about 150 feet in the western part of the State to more than 1000 feet in the central part of the State (Plate 13). The highly-radioactive shale in the West Falls Formation thickens from 25 feet in western Wayne County, the westernmost part of the State, to more than 100 feet in a N-S oriented belt in the west-central part of the State before thinning rapidly to the east (Plate 14). The eastward thickening then thinning of the highly-radioactive shale in the West

Formation is what would be expected if the highly-radioactive shales are organic-rich black shales deposited in shallow water in the western part of an epicontinental sea that pass eastward into shales and siltstones (turbidites) deposited in deeper water in the central part of the sea. The "clean" sandstones and siltstones present in eastern equivalents of the West Valls Formation (Plate 14) include the Elk, Sycamore, and maybe the Benson and Riley sandstones and siltstones. Gas has been produced from the Rhinestreet Member in western West Virginia (Neal, 1979; Dowse, 1980) and from the sandstone and siltstones listed above in north-central West Virginia (Cardwell, 1977).

The Late Devonian transgression continued during deposition of the West Falls Formation. At this time, the western borders of the sea were west of West Virginia. The sea had not yet covered the Cincinnati Arch, for equivalents of the West Falls Formation are not present in central Ohio, or on the crest of the Cincinnati Arch in western Ohio (Schwietering, 1970, 1979; Wallace and others, 1978a, 1978b). Sandstones and siltstones present in the central and eastern parts of the State indicate a continuation of the influx of coarser sediments from the east and progradation of the Catskill clastic wedge into the central part of the State.

The Java Formation is recognized only in the western part of West Virginia. The base of the Java Formation is defined by a thin (up to 30 feet thick) bed of moderately- to highly-radioactive shale that has been correlated with the Pipe Creek Shale of western New York (Neal, 1979; Dowse, 1980). The top of the Java Formation is marked by the base of the highly radioactive shale of the Huron Member of the Ohio Shale. Because the Java Formation cannot be traced into central or eastern West Virginia, its relation to rocks in the eastern part of the State is not well established. It is tentatively correlated with the middle of the Greenland Gap Group (Figure 1).

The Java Formation consists of greenish-gray, gray, dark-gray, very dark-gray and black shale. The Java occurs in the upper part of the "Big White Slate" of the drillers. The Java ranges in thickness from 75 feet in the westernmost part of the State to more than 225 feet in the west-central part of the State (Plate 15).

In West Virginia, the highly radioactive shale in the Java Formation thins from west to east, being 20 to 30 feet thick in the western part of the State and absent in the central part of the State (Plate 16). The highly radioactive shale pinches out eastward into gray to dark-gray shale. Because the formation cannot be recognized in the central or eastern part of the State, no "clean" sandstones or siltstones have been identified as belonging to the Java Formation.

The presence of equivalents of the Java Formation in central and south-central Ohio (Schwietering, 1970, 1979; Wallace and others, 1978a) indicates that the Late Devonian transgression continued during the deposition of the Java Formation. However, the sea had yet to cover the Cincinnati Arch, for Java equivalents are absent on the crest of the arch in west-central Ohio (Schwietering, 1970, 1979) and on the crest of the Nashville Dome in central Tennessee (Wallace and others, 1978a).

The Ohio Shale is divided into the Huron Member and the Cleveland Member (Figure 1). The Huron and Cleveland consist of very dark-gray to black shale with interbeds of gray and greenish-gray shale. The black shale is organic-rich and highly radioactive. In eastern Ohio, eastern Kentucky, and western West Virginia, the black shale of the Ohio Shale intertongues with greenish-gray, gray, and dark-gray shale, siltstone, and sandstone. In northwestern Ohio, the upper part of the interbedded gray shale, siltstone, and sandstone is called the Chagrin Shale. This name has been applied to rocks of similar lithology and stratigraphic position in western West Virginia (Neal, 1979).

The Ohio Shale is correlated with the upper part of the Greenland Gap Group and the Hampshire Formation is eastern outcrops (Figure 1). The upper part of the Greenland Gap Group has been described. The Hampshire Formation consists of red, green, and gray shale, siltstone, and sandstone, and conglomeratic sandstone (McIver, 1961; Dennison and Naegle, 1963).

The Huron is the basal member of the Ohio Shale and it can be identified as far east as central West Virginia. The "Brown Shale Zones II and III" of Martin and Nuckols (1976) and the upper part of the "Brown Shale" of Patchen and Larese (1976) and Bagnall and Ryan (1976) are equivalent to the Huron Member. The Cleveland is the upper member of the Ohio Shale. It is only present in Wayne and Cabell Counties in westernmost West Virginia. Where the Cleveland Member is absent, the Ohio Shale cannot be consistently separated from the overlying Bedford Shale on gamma-ray logs. The Ohio Shale-Bedford Shale interval thickens from 750 feet in westernmost West Virginia to more than 3000 feet in the central part of the State (Plate 17).

Except in Wayne and Cabell Counties where highly-radioactive shale of the Cleveland Member is present, the highly-radioactive shale mapped on Plate 18 represents organic-rich black shale in the Huron Member. While as much as 500 feet of highly-radioactive shale is present in the Ohio Shale in westernmost West Virginia, highly-radioactive shale is absent east of central West Virginia. Therefore no member of the Ohio Shale is recognized east of the pinchout of the highly-radioactive shale. The westernmost "clean" sandstones and siltstones mapped on Plate 18 are equivalents of the Hampshire Formation, whereas in the central part of the State sandstones and siltstones as old as Speechley and Balltown and maybe Bradford occur in this interval. Gas and oil are produced from the Huron Member in western West Virginia (Neal, 1979; Dowse, 1980), and from sandstones and siltstones in Greenland Gap and Hampshire equivalents of the Ohio Shale in central West Virginia (Cardwell, 1977).

The presence of the Ohio Shale on the crest of the Cincinnati Arch (Moses, 1922; Schwietering, 1970, 1979) and the Chattanooga Shale (the lower part of which is a southern equivalent of the Ohio Shale) on the crest of the Nashville Dome (Conant and Swanson, 1961) indicates that the Late Devonian transgression continued during the deposition of the Ohio Shale. During this time, the Cincinnati Arch was covered and the epicontinental seas in the Michigan, Illinois, and the Appalachian basins were joined. The sandstones and siltstones in the western part of the State indicate a continuation of the influx of coarser sediments from the east and the progradation of the Catskill clastic wedge into western West Virginia.

3. MODEL OF SEDIMENTATION

Middle and Upper Devonian rocks in West Virginia were deposited in a shallow to moderately deep epicontinental sea. These rocks either belong to the Catskill clastic wedge or they pass laterally into it. Land along the eastern margin of the continent was the primary source of the sediments making up these rocks. This land may have been formed by the collision of North America with a microcontinent in the manner described by Harris and Bayer (1979), Cook and others (1979), and Williams and others (1980).

Heckel (1972, pages 268-270) suggests that the epicontinental sea between Australia and New Guinea is an analog of the epicontinental sea that covered the Appalachian basin and extensive parts of the interior of North America during the Devonian; New Guinea would correspond to the land along the margin of the continent, Australia would correspond to the interior of the continent. The sea between Australia and New Guinea is made up of the Arfura Sea, the Gulf of Carpentaria, and part of the Sahul Shelf. Nowhere in the Arfura Sea or the Gulf of Carpentaria is the sea greater than 600 feet deep, and over much of this area, the sea is less than 300 feet deep (Heckel, 1972; National Geographic Atlas, 1974). I think that this analogy is an accurate one. As pointed out by Audley-Charles and others (1977), the Catskill delta was formed on continental crust by sediments carried toward the interior of the continent from land along the margin of the continent. Modern deltas being built seaward across continental shelves, continental slopes, and continental rises are not good analogs of the Catskill clastic wedge, for these features are being built seaward into very deep water over oceanic crust.

In the model proposed in this report, the Catskill clastic wedge in West Virginia formed in an epicontinental sea similar to the Arfura Sea and Gulf of Carpentaria between Australia and New Guinea. The Devonian sea was

shallow, probably nowhere deeper than 600 feet, and bordered by land to the east and west. Early in the Late Devonian, land may have been present south of West Virginia. During the Late Devonian, a rise in sea level caused this sea to transgress onto the land surrounding the sea. However, in the eastern and central parts of the Appalachian basin, the rates of sedimentation were such that in spite of subsidence and the rise of sea level, the sea never became deep, and the clastic wedge prograded from the continental margin toward the interior of the continent. The land along the eastern margin of the continent was underlain by sedimentary and low grade metamorphic rocks (McIver, 1961; Heald, 1980). In the interior of the continent there existed a low-lying relatively smooth surface (peneplain) that was periodically covered by water during periods of high sea level in the Middle and Late Devonian. The smooth nature of this surface is indicated by the paraconformities present in Silurian and Devonian rocks exposed on, or around, the Cincinnati Arch. Because of its very low relief and the nature of the underlying rocks (primarily limestone and shale), the interior of the continent only supplied minor amounts of sediments to the Catskill clastic wedge and associated rocks.

Middle and Upper Devonian rocks studied during this project can be divided into two major facies: a clastic wedge facies, and a platform facies. The clastic wedge facies is divided into three facies: 1) red bed facies; 2) gray shale and sandstone facies; 3) dark-gray shale and siltstone facies. All the rocks deposited on the platform are placed into one facies; the black shale facies.

Facies 1 contains red, gray, and green shale, siltstone, sandstone, and conglomerate deposited in terrestrial and near-shore marine environments along the interior shores of the land along the margin of the continent. The Hampshire Formation and the uppermost part of the Greenland Gap Group belong

to this facies. In West Virginia, this facies is restricted to the eastern and upper part of the clastic wedge (Figure 2).

Facies 2 contains gray shale, sandstone, and some siltstone. These rocks were deposited in shallow- to moderately-deep marine environments offshore from facies 1. In West Virginia, rocks of this facies are found west of and beneath rocks of facies 1 (Figure 2). Most of the Greenland Gap Group belongs to this facies. Some of the sandstones and siltstones within this facies appear to be turbidites deposited from turbidity currents that flowed into the shallow epicontinental sea from the land along the margin of the continent (McIver, 1961, 1970; Cheema, 1977; Lundegard and others, 1978).

Facies 3 contains dark-gray shale and siltstone deposited in the deepest part of the epicontinental sea. In West Virginia, rocks in this facies are found west of and beneath rocks of facies 2 (Figure 2). The siltstones in this facies also appear to be turbidites (Avary, 1978; Lundegard and others, 1978; Avary and Dennison, 1980). This facies is characterized by the Brallier Formation.

Facies 3 intertongues westward with the platform facies, the black shale facies. This facies contains organic-rich black shale, greenish-gray shale, gray shale, and thin beds of argillaceous limestone deposited in shallow- to moderately-deep marine to brackish-water environments developed on the platform in the western part of the epicontinental sea (Figure 2). The black shale facies is not considered to be part of the clastic wedge. Instead, the black shale facies is thought to be analogous to a platform-limestone facies that contained very shallow near-shore to moderately deep offshore environments. This black shale facies was deposited on and adjacent to the craton and eventually surrounded and covered positive elements of the craton.

During the deposition of the Catskill clastic wedge, the rate of sedimentation exceeded the combined influence of subsidence in the basin and

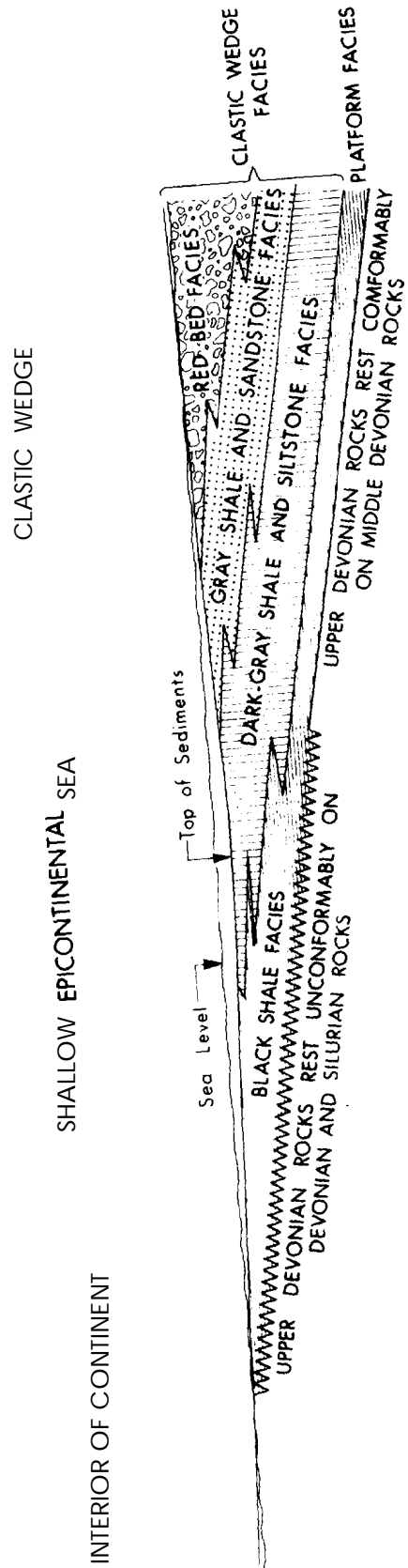


Figure 2. Idealized cross section showing relations of facies in West Virginia. in Upper Devonian rocks

rising sea level so that the facies in the clastic wedge migrated inland over the platform facies in the western part of the epicontinental sea (Figure 2).

As mentioned above, some of the sandstones and siltstones in the Catskill clastic wedge may have been transported into the deeper part of the epicontinental sea by turbidity currents flowing from the shallow water in the eastern part of the sea. Cheema (1977) thought that the siltstone and sandstones in the Benson sandstone zone (lower part of the Greenland Gap Group) in north-central West Virginia were formed in the mid-fan part of shallow-water submarine fans. The fans were formed in part by turbidity currents flowing west from an eastern high area. On the basis of trace fossils in the Benson sandstone, he suggested that they were formed in neritic water (water less than 600 feet deep). Lundegard and others (1978) considered the siltstones in the Brallier Formation to have been deposited from low-density turbidity currents caused by storm agitation or river discharge. They did not find evidence for submarine fans, and they thought that the turbidites were deposited in water less than 1000 feet deep. Avary (1978) and Avary and Dennison (1980) considered the Back Creek Siltstone to contain turbidites deposited on a submarine fan. The Back Creek Siltstone is present in the lower part of the Brallier Formation along the Allegheny Front in east-central West Virginia.

That the turbidites in the Catskill clastic wedge may be the result of storm agitation as suggested by Lundegard and others (1978) may be accounted for in the following way. During the Devonian, the West Virginia portion of the Appalachian basin was located between 5 and 20 degrees south of the equator (Woodrow and others, 1973; Habicht, 1979; Scotese and others, 1979; Bambach and others, 1980). If we assume that West Virginia was between 10 and 15 degrees south latitude, then the interior of the continent would have straddled the equator, while the southern (now eastern) margin of the continent would have been between 15 and 25 degrees south latitude. At these latitudes, the

epicontinental sea that covered the Appalachian basin would lie between the equatorial doldrums and the southern horse latitudes. Between these latitudes, the southeast trade winds would blow north across the epicontinental sea toward the interior of the continent. If storms similar to hurricanes formed over the epicontinental sea, they would have moved southwest onto the land along the margin of the continent. As the storms moved on land, they would have stirred up sediments along the coast and produced turbid layers and turbidity currents that would have flowed north toward the center of the epicontinental sea.

Hayes (1967) described the effects of two hurricanes (Carla, 1961; and Cinday, 1963) on the beach and shelf along the Texas coast south of Corpus Christi. During the flood of the storm surge, water piled up along the beach and on the tidal flats behind the beach. During the ebb of the storm surge, very rapid and strong currents carried sediment-laden water out onto the shallow water covering the shelf along the Texas coast where turbidites were deposited.

Storm-generated shallow-water turbidites have also been identified in ancient deposits. Hamblin and Walker (1979) recognized such deposits in Jurassic rocks in southern Alberta and southeastern British Columbia. Cant (1980) identified storm-generated turbidites in Silurian-Devonian rocks of Nova Scotia. These Silurian-Devonian rocks are similar to rocks making up the Catskill clastic wedge in West Virginia. Comparing the siltstones and sandstones present in the Catskill clastic wedge to the deposits described by Hayes (1967), Hamblin and Walker (1979), and Cant (1980) suggests to me that some of the siltstones and sandstones in the Catskill clastic wedge in West Virginia are shallow- to moderately-deep storm-generated turbidites.

West of the clastic wedge, the black shale facies was deposited in shallow- to moderately-deep marine or brackish-water that covered the platform bordering exposed parts of the Nashville Dome and the Cincinnati-Findlay-Algonquin Arch,

(Conant and Swanson, 1961; Schwietering, 1970). Fossils found in the black shale facies, such as inarticulate and articulate brachiopods, conodonts, radiolaria (Foreman, 1959, 1963), cephalopods, crinoids (Wells, 1941, 1947), and scolecodonts, indicate that the salinity of the water in the epicontinental sea over the interior platform was within the range of normal marine to brackish water. The salinity in this shallow equatorial sea remained within the normal-marine to brackish-water salinity range because of a large influx of fresh water by precipitation and runoff. Storms in the equatorial doldrums probably supplied large quantities of fresh water to the sea. Runoff from surrounding land areas not only supplied fresh-water, but also nutrients to help maintain the biological community that lived in the sea.

4. THERMAL MATURITY, SOURCE ROCKS, AND RESERVOIRS

Claypool and others (1978, page 54) wrote: "In the Appalachian basin, formation of natural gas in sedimentary rocks is largely a result of the thermochemical conversion of solid and liquid organic matter to methane. This conversion process is in its early stages in rocks of the western part of the basin, and approaches completion in the east." Studies by Harris (1978) and Harris and others (1978) on regional variations in the color of conodonts also show that the thermal maturity of the organic matter in the Appalachian basin increases from the west to the east. Because most of the Appalachian basin has not been subjected to magmatic intrusions, the thermal maturity of the organic matter in the basin west of the intensely folded rocks in the east is primarily a function of depth of burial. The deeper material is buried, the higher the thermal maturity. Devonian rocks in the central and eastern parts of the Appalachian basin were more deeply buried beneath younger rocks than in the western part of the basin and on the Nashville Dome and the Cincinnati-Findlay-Algonquin Arch (Harris and others, 1978).

The nature of the gas produced from Devonian rocks in the Appalachian basin also reflects the eastward increase in thermal maturity in the basin. In the western part of the basin (where the black shale facies is dominant), the gas in the Devonian shale is moderately wet. To the east, the gas becomes very wet, then moderately wet, then dry, and in the easternmost part of the basin (where the clastic wedge is dominant) very dry (Claypool and others, 1978). Combining these studies of the thermal maturity and hydrocarbon geochemistry with knowledge of the distribution of rock types in the basin gives some indication of the location of source rocks, reservoirs, and types of hydrocarbon to be found in the basin.

In the western part of the Appalachian basin, the Middle and Upper Devonian section is relatively thin (less than 1500 feet thick) and organic-rich black shales make up more than 50% of the section. The black shale is a low-grade oil shale in the early stage of thermal maturity, and the gas present in these shales is moderately wet (Claypool and others, 1978). This gas was probably formed and trapped within the black shale that produced it. In fact, these shales have probably not even supplied gas to the overlying Berea Sandstone. Claypool (1980) reported that on the basis of a study of the hydrocarbon geochemistry of oils derived from Devonian shales, oils in the Mississippian Berea Sandstone on the western margin of the Appalachian basin migrated from Devonian source rocks located 100 km to the east.

In the central part of the Appalachian basin, Middle and Upper Devonian rocks are 1500 to 4000 feet thick, but organic-rich black shales are present only in the lower half of this section. Dark-gray and gray shale, siltstone, and sandstone are present in the middle and upper part of the section, and some red beds are present at the very top of the section. These rocks were more deeply buried, and consequently their thermal maturity is greater than rocks to the west. The gas present in these rocks is moderately wet to very wet (Claypool and others, 1978).

In the eastern part of the Appalachian basin, Middle and Upper Devonian rocks are from 4000 to more than 7000 feet thick, and organic-rich black shales are present only in the lower third of the section. Dark-gray and gray shale, siltstone, and sandstone are present in the middle and upper part of the section, and red beds are present throughout the upper third of the section. The thermal maturity of the organic matter in these rocks is greater than it is in other parts of the Appalachian basin. Consequently, the gas from these rocks is dry to very dry (Claypool and others, 1978).

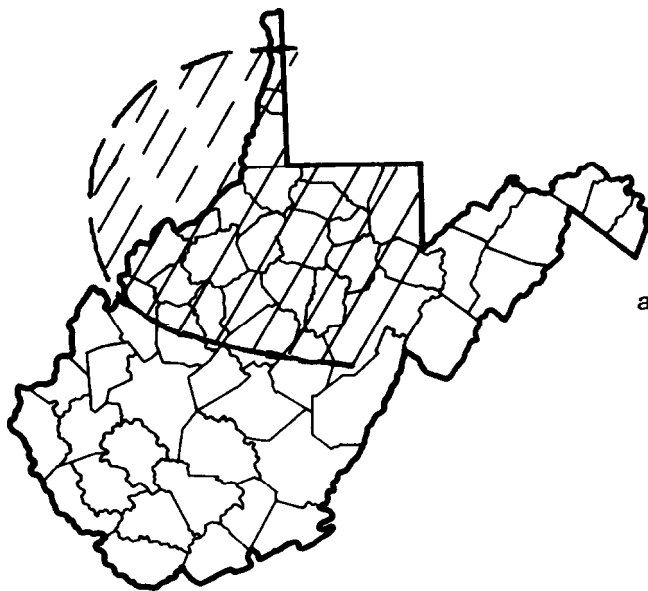
The oil and gas in the central and eastern parts of the Appalachian basin are probably products of local migration. Claypool (1980) in his report on the geochemistry of oils derived from Devonian shales in the Appalachian basin writes: ". . . the easternmost oil occurrences in lenticular sandstones were products of very local migration from adjacent shales. In the eastern part of the basin, the advanced stage of thermal maturity of both oils and extractable hydrocarbons in adjacent source rocks suggest that hydrocarbons, both in the reservoir and source rock, underwent parallel thermal maturation after migration and emplacement of the oil."

5. OIL AND GAS PRODUCTION FROM UPPER DEVONIAN ROCKS IN WEST VIRGINIA

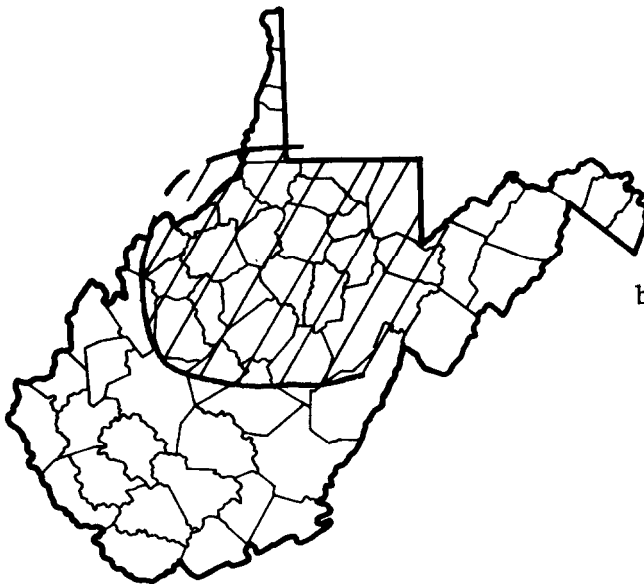
The following summary of oil and gas production from Upper Devonian rocks in West Virginia is based upon studies by Cardwell (1977), Neal (1979), and Dowse (1980). Figure 1 shows the tentative correlation of the subsurface sandstones with formations recognized in outcrops along the Allegheny Front.

Sandstones and siltstones of the Hampshire Formation (primarily the Fifth, Gordon, Gordon Stray, Fourth, Fifty-foot, and Thirty-foot) and the Greenland Gap Group (primarily the Benson, Riley, Speechley, and Balltown) produce oil and natural gas west of the Allegheny Front and north of Pocahontas, Webster, Nicholas, Clay, Kanawha, and Jackson Counties (Figures 3a and 3b). South and west of the producing area, these sandstones and siltstones pinch out into the dark-gray shale and siltstone facies. Siltstones in the Brallier Formation (Elk and Sycamore) produce natural gas in Randolph, Barbour, and Upshur Counties (Figure 3c).

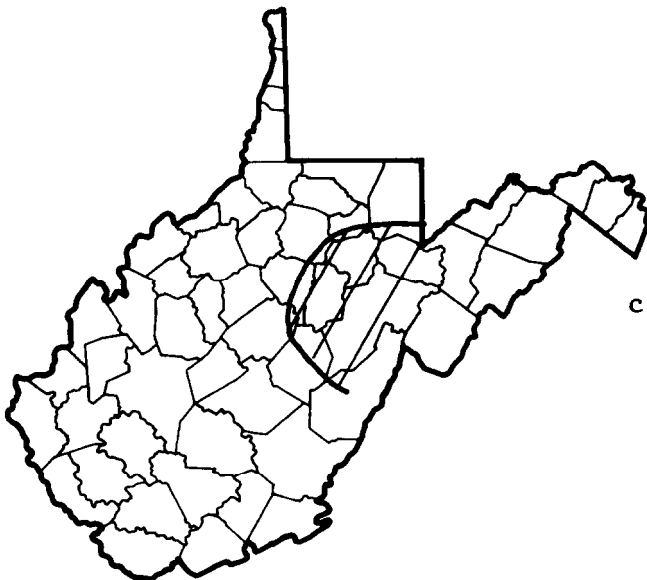
In the western part of the State, oil and gas are produced from the organic-rich black shale in the Huron Member of the Ohio Shale and the Rhine-street Member of the West Falls Formation (Figure 4a). Some gas is produced from the organic-rich black shale in the Genesee Formation and the Marcellus Shale in Gilmer County (Figure 4b).



a) Oil and gas production from sandstones and siltstones in the Hampshire Formation.



b) Oil and gas production from sandstones and siltstones in the Greenland Gap Group ("Chemung" Formation).



c) Gas production from siltstones in the Brallier Formation.

Figure 3. Oil and gas production from Upper Devonian rocks.

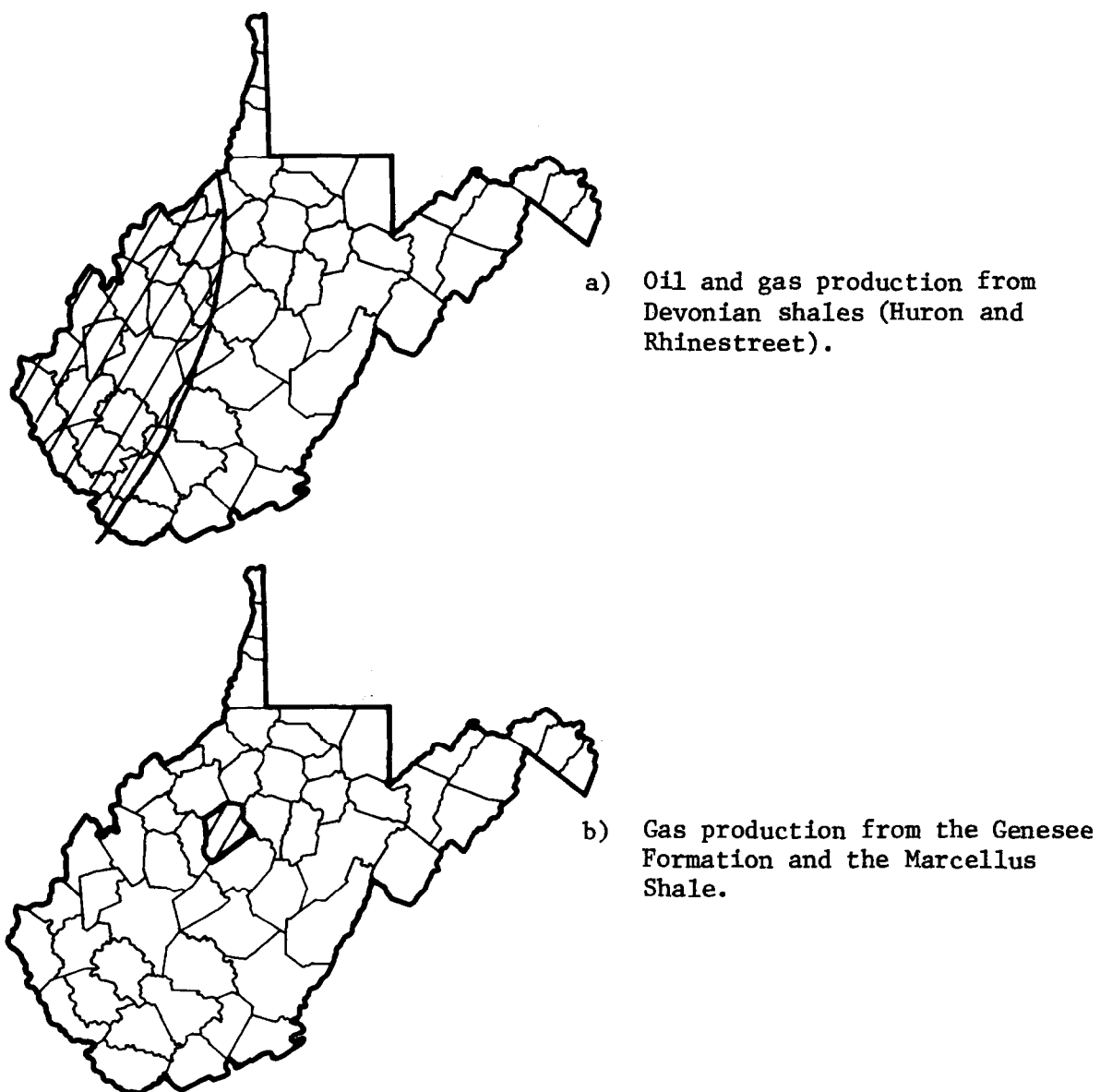


Figure 4. Oil and gas production from Middle and Upper Devonian rocks.

6. SUGGESTED AREAS FOR EXPLORATION FOR OIL AND GAS

On the basis of his studies, Neal (1979) came to the conclusion that there is a sufficient amount of organic-rich black shale in the Huron Member of the Ohio Shale and the Rhinestreet Member of the West Falls Formation to warrant exploration in central and eastern Mingo, Logan, and Boone Counties, and western McDowell, Wyoming, and Raleigh Counties. The most promising areas for exploration would be where fractures are associated with folds, faults, and lineaments. He also suggested that wells be drilled to expand the producing areas in existing fields in southwestern West Virginia (Figure 5a). In those fields only producing from the Huron, he suggested that exploratory wells be drilled below the Huron to test the Rhinestreet.

Dowse (1980) suggested that exploration for gas from the Huron Member of the Ohio Shale and the Rhinestreet Member of the West Falls Formation should be in areas where fractures are associated with structural anomalies in Mason, Putnam, Jackson, and western Wood Counties (Figure 5b). She also suggested that in those parts of the Midway-Extra and Cottageville (Mt. Alto) Fields where wells have not been drilled below the Huron, that wells be drilled deeper to test the organic-rich black shale in the older Rhinestreet. In addition, she noted that in the Elk-Poca (Sissonville) Field the Oriskany Sandstone was the principle target for gas and that the potential for gas production from the younger Devonian shales in this field has not been thoroughly tested.

Schwietering (1980) suggested that thick zones of interbedded siltstone and shale in the Upper Devonian rocks in central and southern West Virginia may be potential reservoirs of natural gas (Figure 5c). Potter and others (1980) also suggested that siltstones in the deeper part of the basin are targets for natural gas exploration. The siltstones are distal turbidites

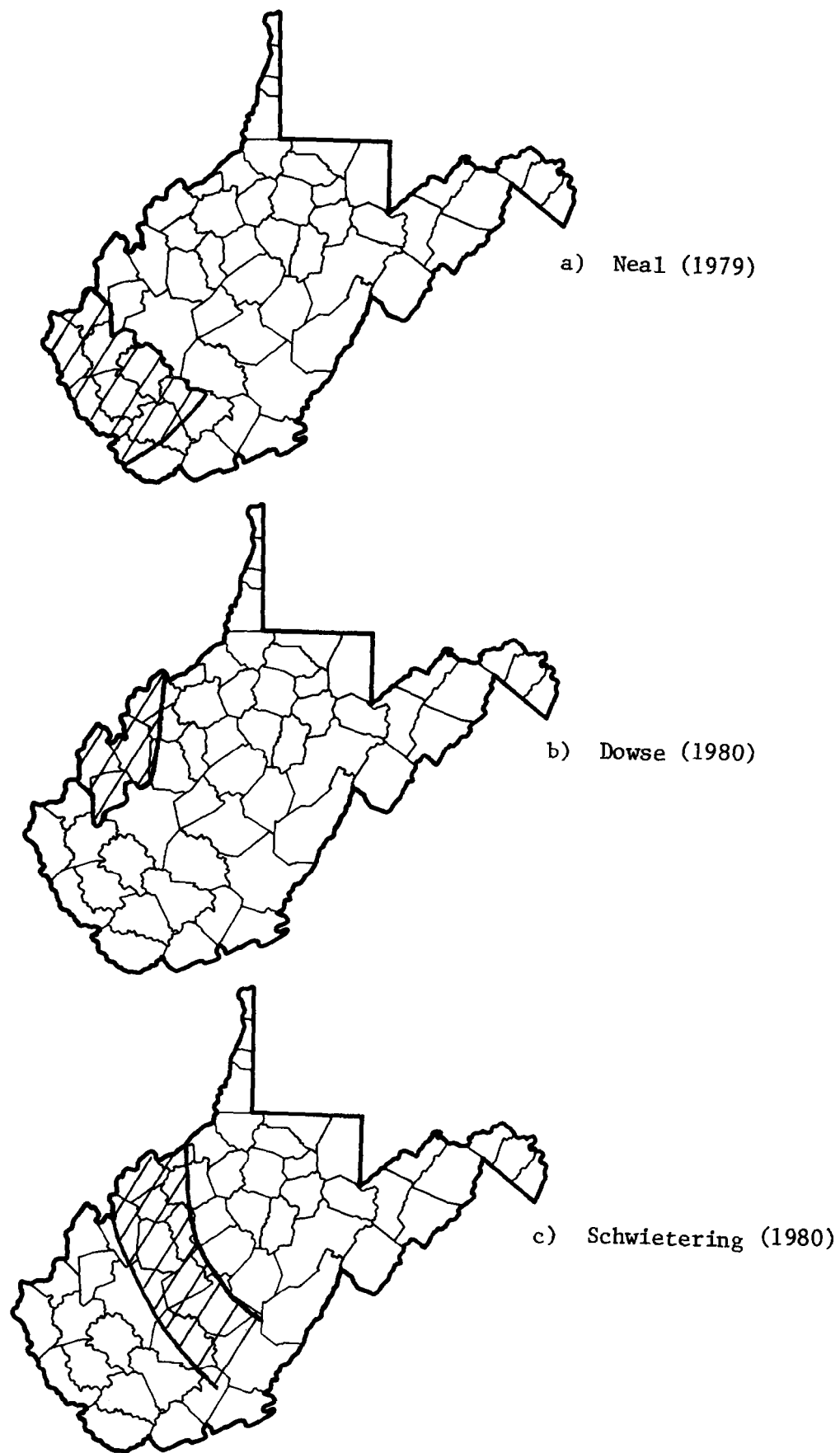


Figure 5. Suggested areas for exploration for natural gas in Devonian shales and siltstones.

that are interbedded with dark-gray shale and overlie organic-rich black shale. The dark-gray shale and the black shale may both be source rocks for gas that might accumulate in the fractures in the siltstone and shale. Potential drilling sites are areas where thick zones of interbedded siltstone and shale are cut by fractures associated with folds, faults, and lineaments. It is suggested that the entire zone of interbedded siltstone and shale be fractured, not just selected siltstones.

The oil and gas production from Devonian shales and Greenland Gap ("Chemung") siltstones in Pleasants, Ritchie, Wirt, Roane, Calhoun, eastern Kanawha, and western Fayette Counties may be from such thick zones of interbedded siltstone and shale. For this production occurs in the area where the deeper-water facies (reservoir rocks) of the Catskill clastic wedge intertongues with, and overlies, the platform facies (source rocks) of the western part of the Appalachian basin.

7. SUMMARY

During the Devonian, an epicontinental sea was present in the Appalachian basin. The Catskill clastic wedge was formed in the eastern part of the basin by sediments derived from land along the margin of the continent.

Three facies are recognized in the Catskill clastic wedge: 1) a red bed facies deposited in terrestrial and near-shore marine environments; 2) a gray shale and sandstone facies deposited in a shallow- to moderately-deep marine environment; 3) a dark-gray shale and siltstone facies deposited in the deepest part of the epicontinental sea. Turbidites, possibly deposited from storm-generated turbidity currents, are present in facies 2 and 3. Because the rate at which the clastic wedge formed exceeded the rate of subsidence of the basin and the rise in sea level during the Late Devonian, the Catskill clastic wedge intertongued with, and prograded inland over, shallow- to moderately-deep platform deposits that consisted of organic-rich black shale, gray and greenish-gray shale, and thin beds of argillaceous limestone. These platform deposits make up the black shale facies. Rocks in the black shale facies formed in marine to brackish water that covered the interior of the continent.

Oil and natural gas are now being produced from Devonian shales in the western part of West Virginia and from Upper Devonian sandstones and siltstones in the north-central part of the State. It is suggested that in addition to extending known areas of gas production, that drilling for natural gas be conducted in areas underlain by organic-rich shales and thick zones of interbedded siltstone and shale in the Devonian section in central, southern, and western West Virginia. The most promising areas for exploration are those areas where fractures are associated with folds, faults, and lineaments.

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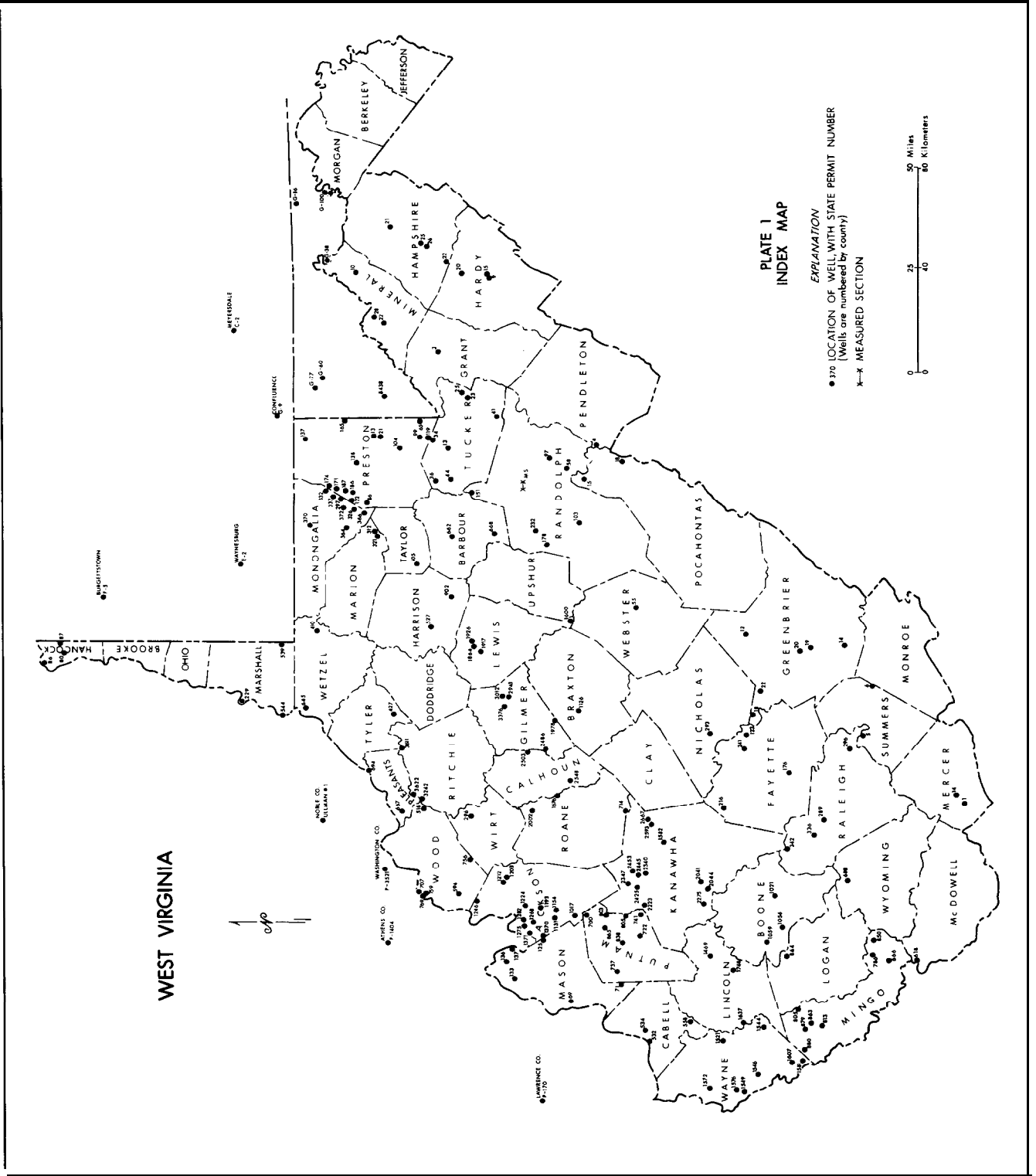
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9. PLATES



WEST VIRGINIA

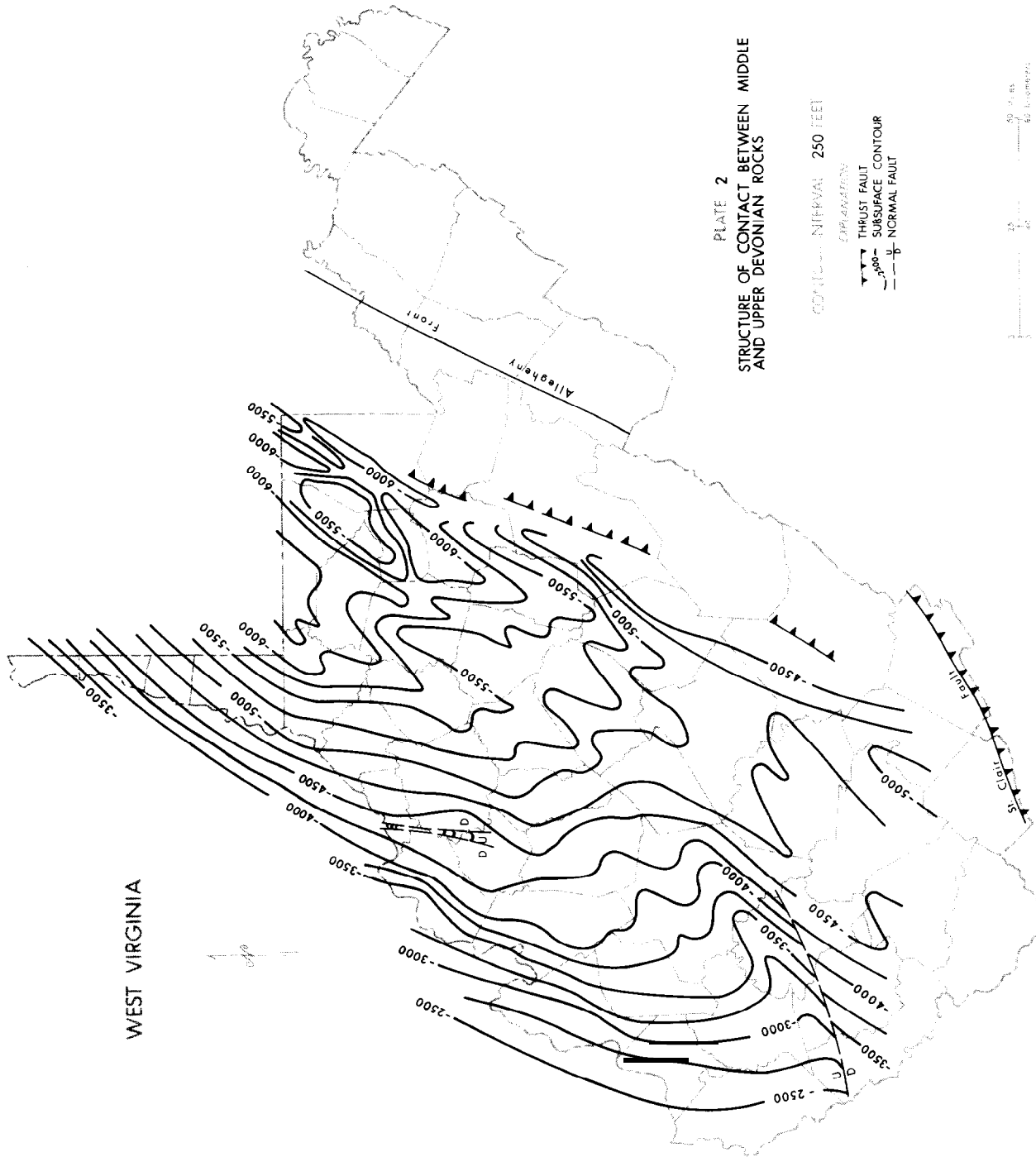


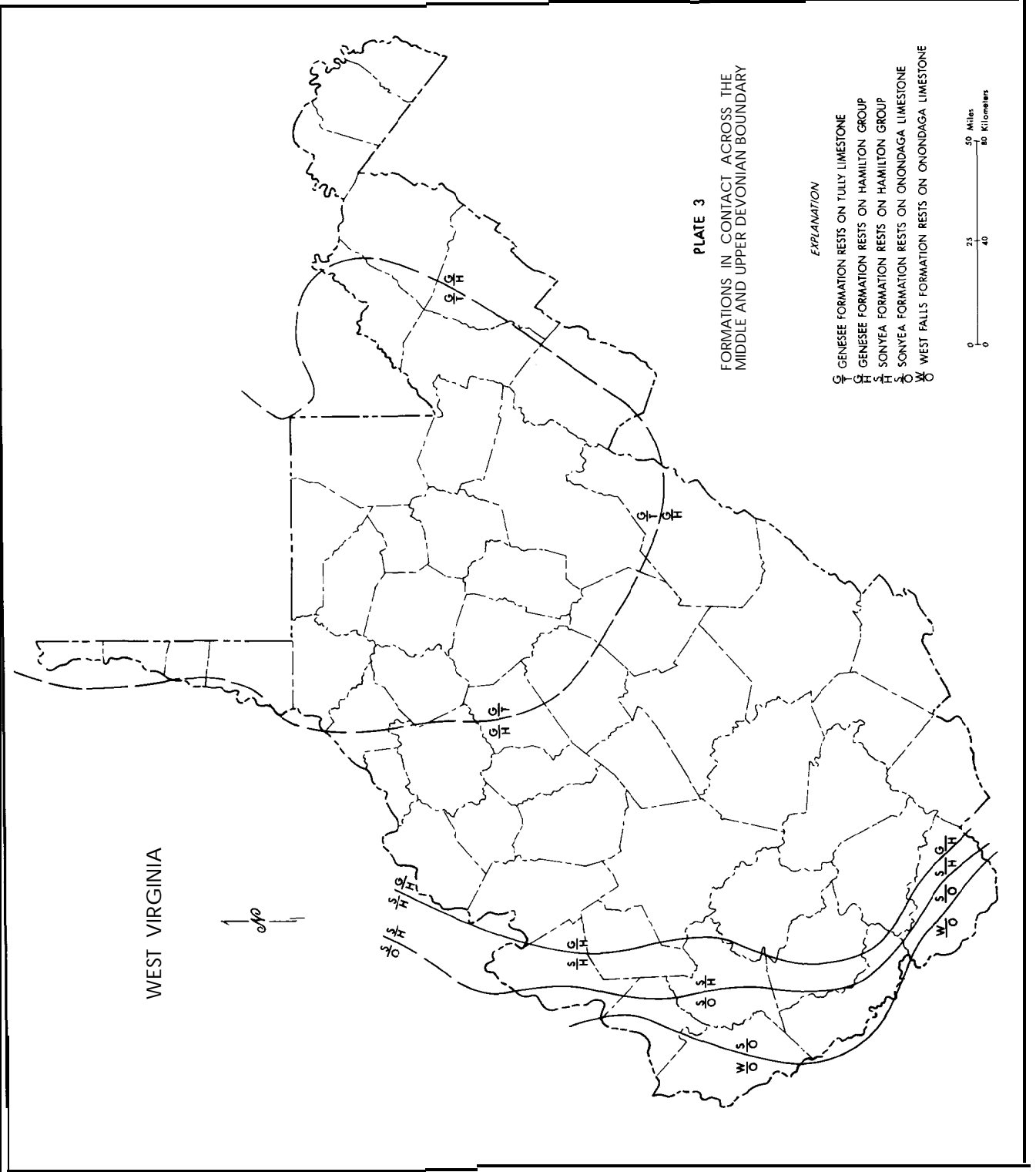
PLATE 2
STRUCTURE OF CONTACT BETWEEN MIDDLE
AND UPPER DEVONIAN ROCKS

CONTOUR INTERVAL 250 FEET

EXPLANATION

- THRUST FAULT
- SUBSURFACE CONTOUR
- NORMAL FAULT





WEST VIRGINIA

1000

2000

3000

4000

5000

6000

7000

7000

6000

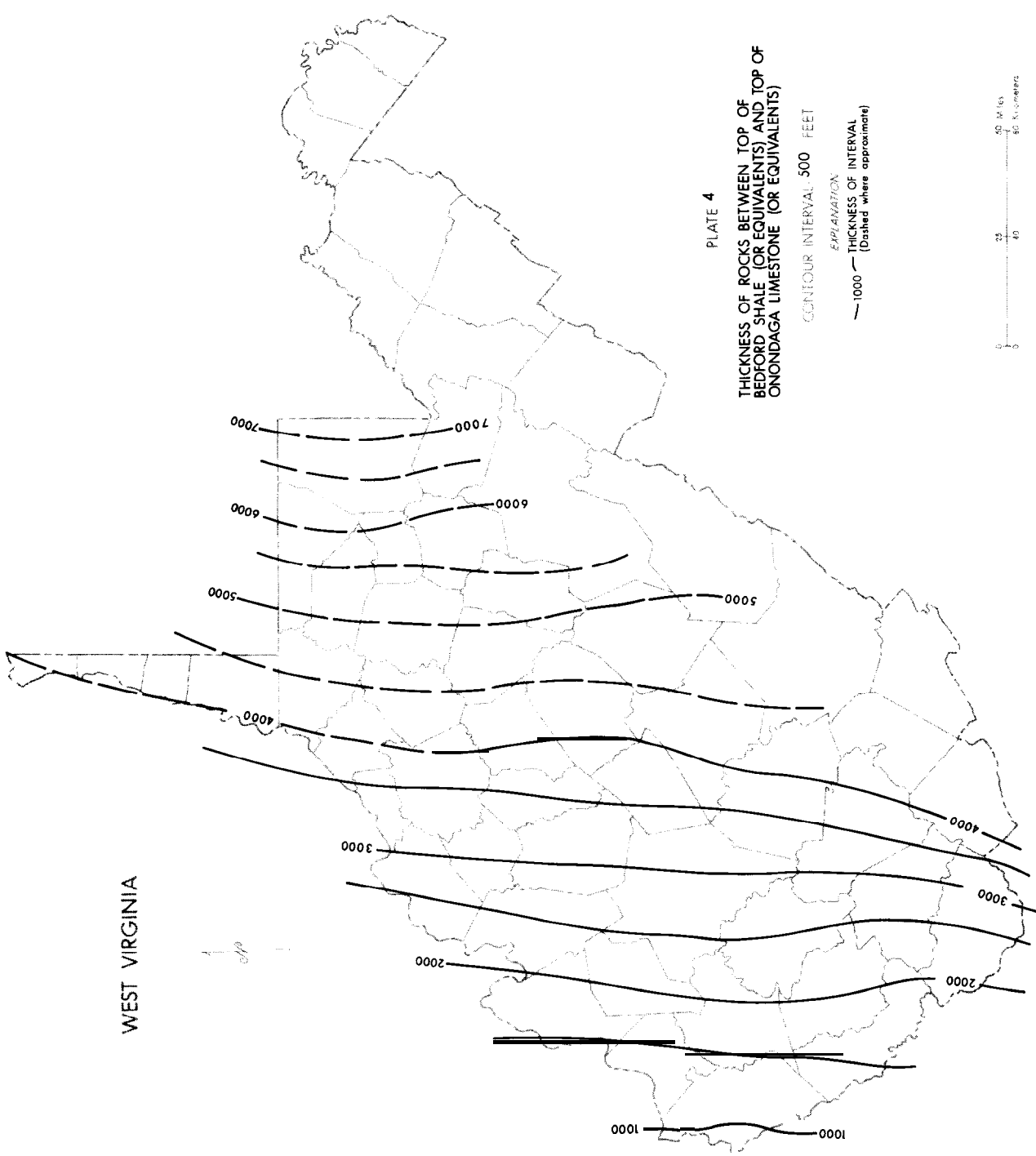
PLATE 4

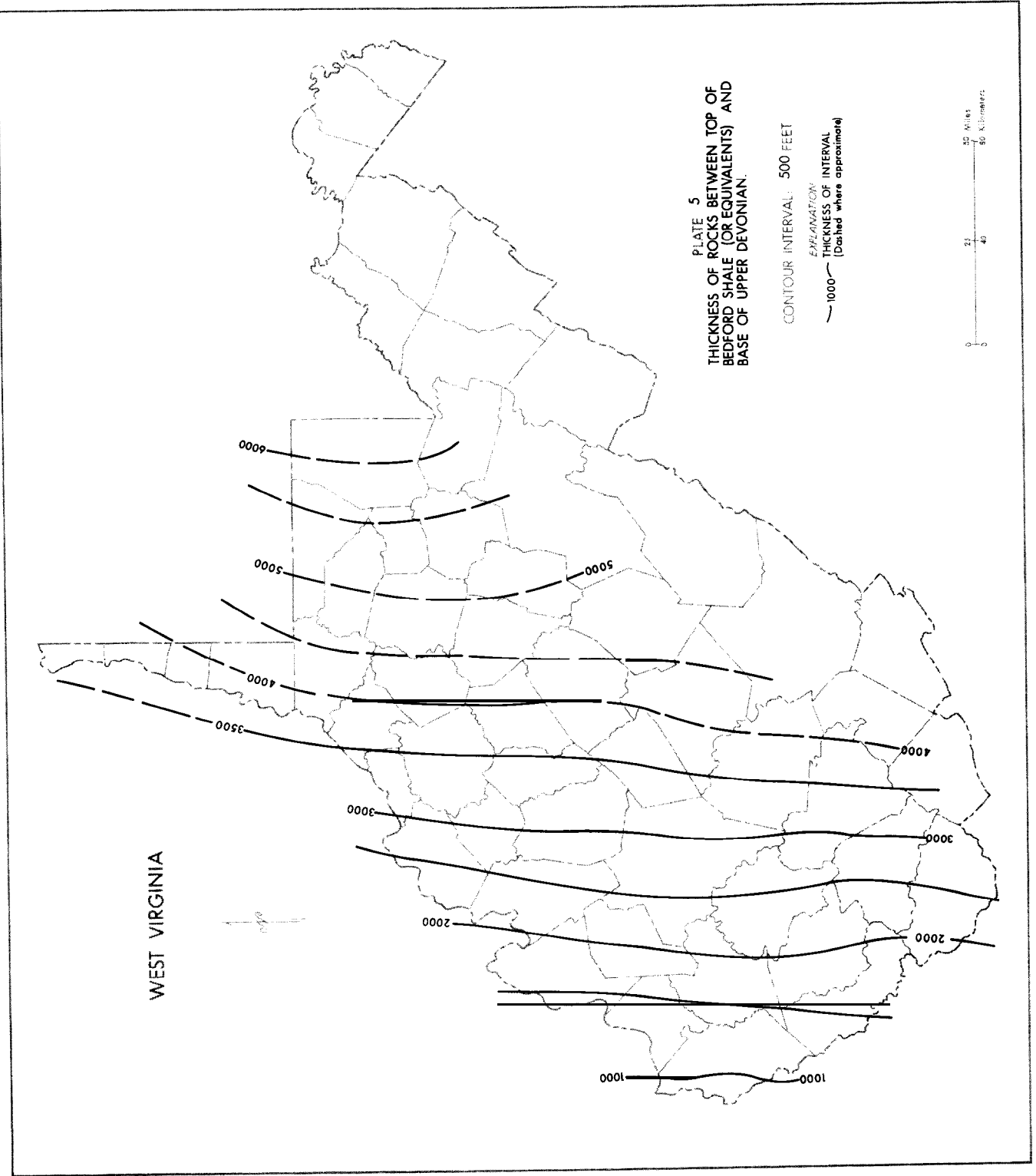
THICKNESS OF ROCKS BETWEEN TOP OF
BEDFORD SHALE (OR EQUIVALENTS) AND TOP OF
ONONDAGA LIMESTONE (OR EQUIVALENTS)

CONTOUR INTERVAL: 500 FEET

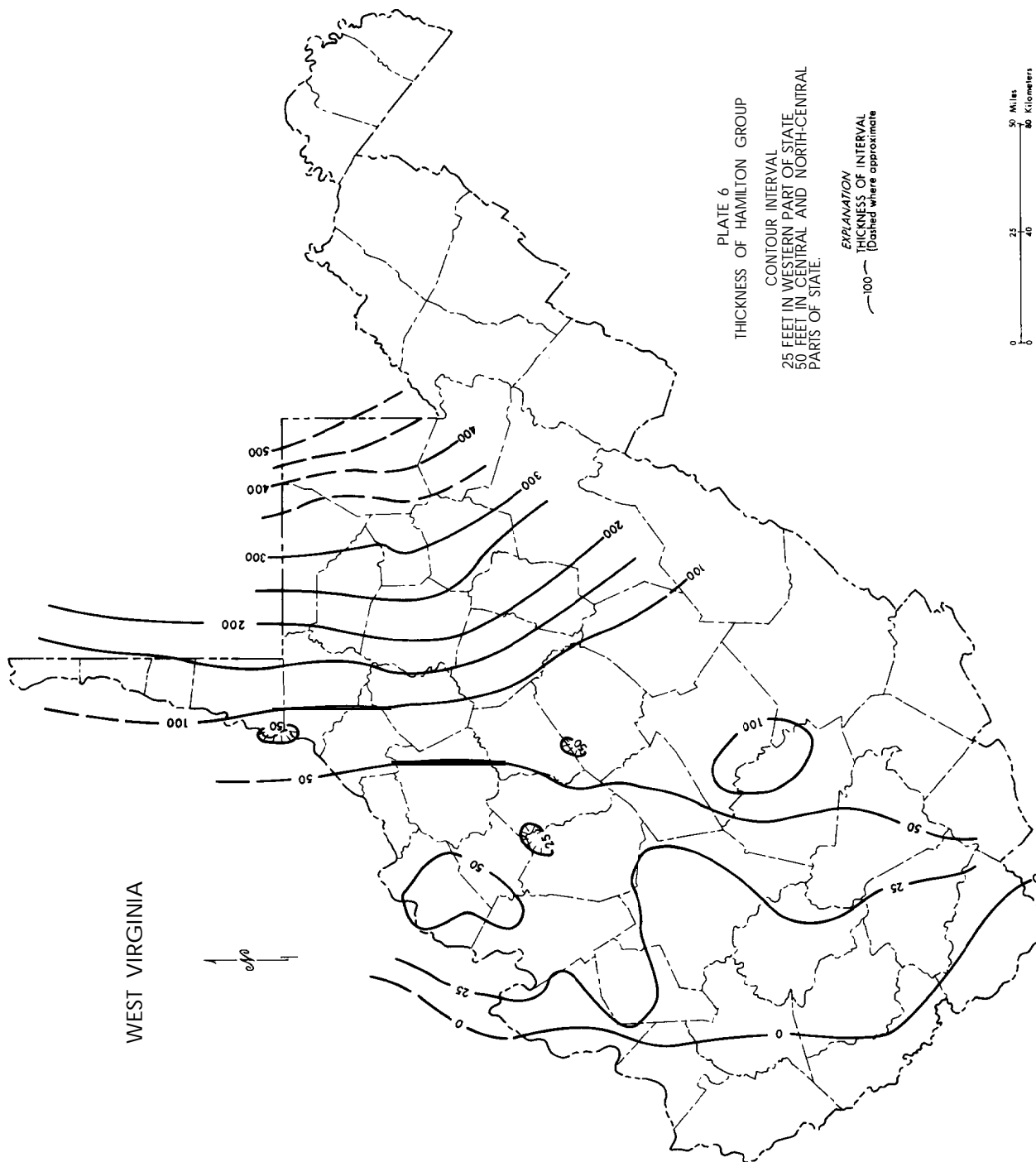
EXPLANATION
— 1000 — THICKNESS OF INTERVAL
(Dashed where approximate)

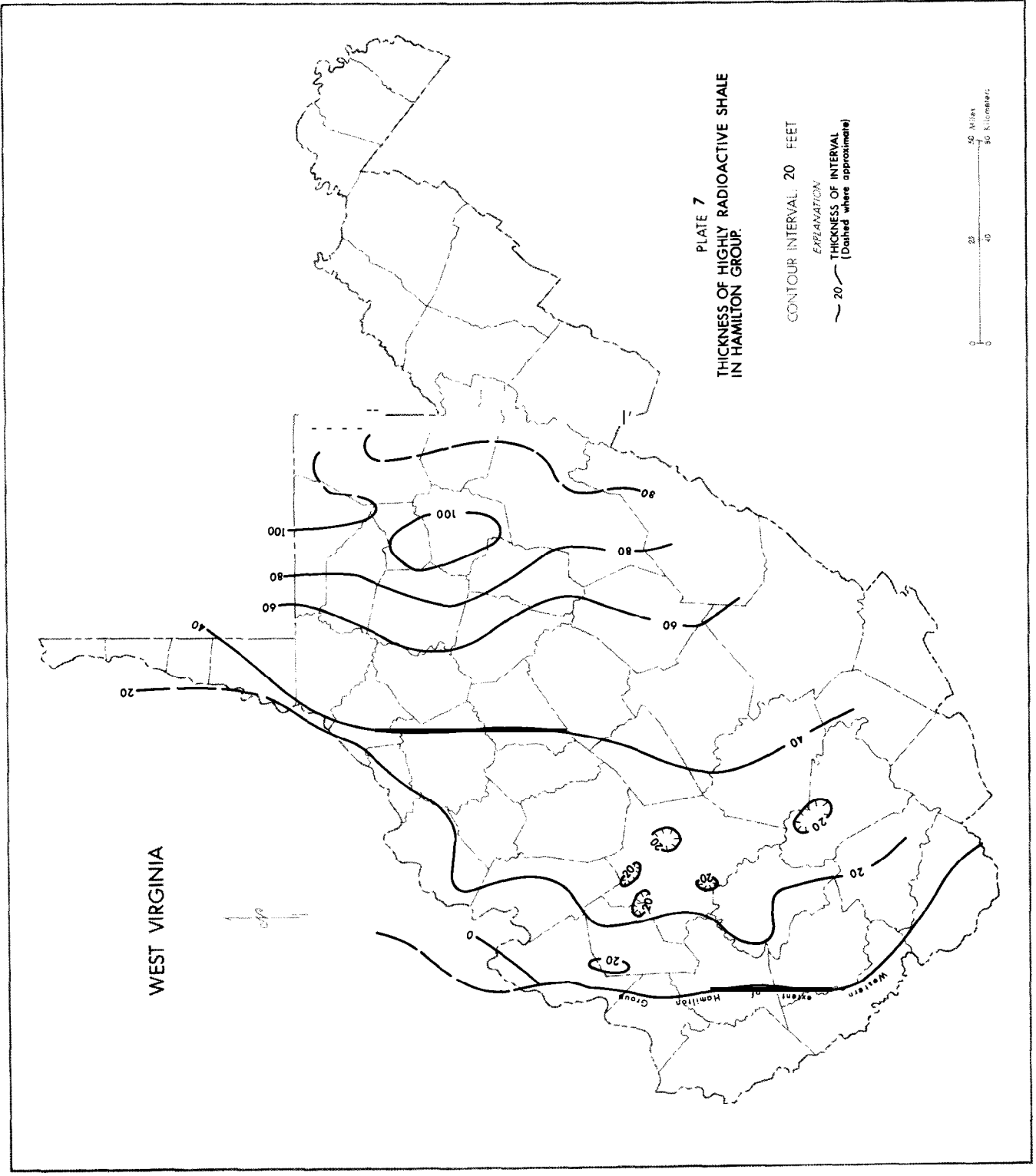
0 20 40 Miles
0 20 40 Kilometers





WEST VIRGINIA





WEST VIRGINIA

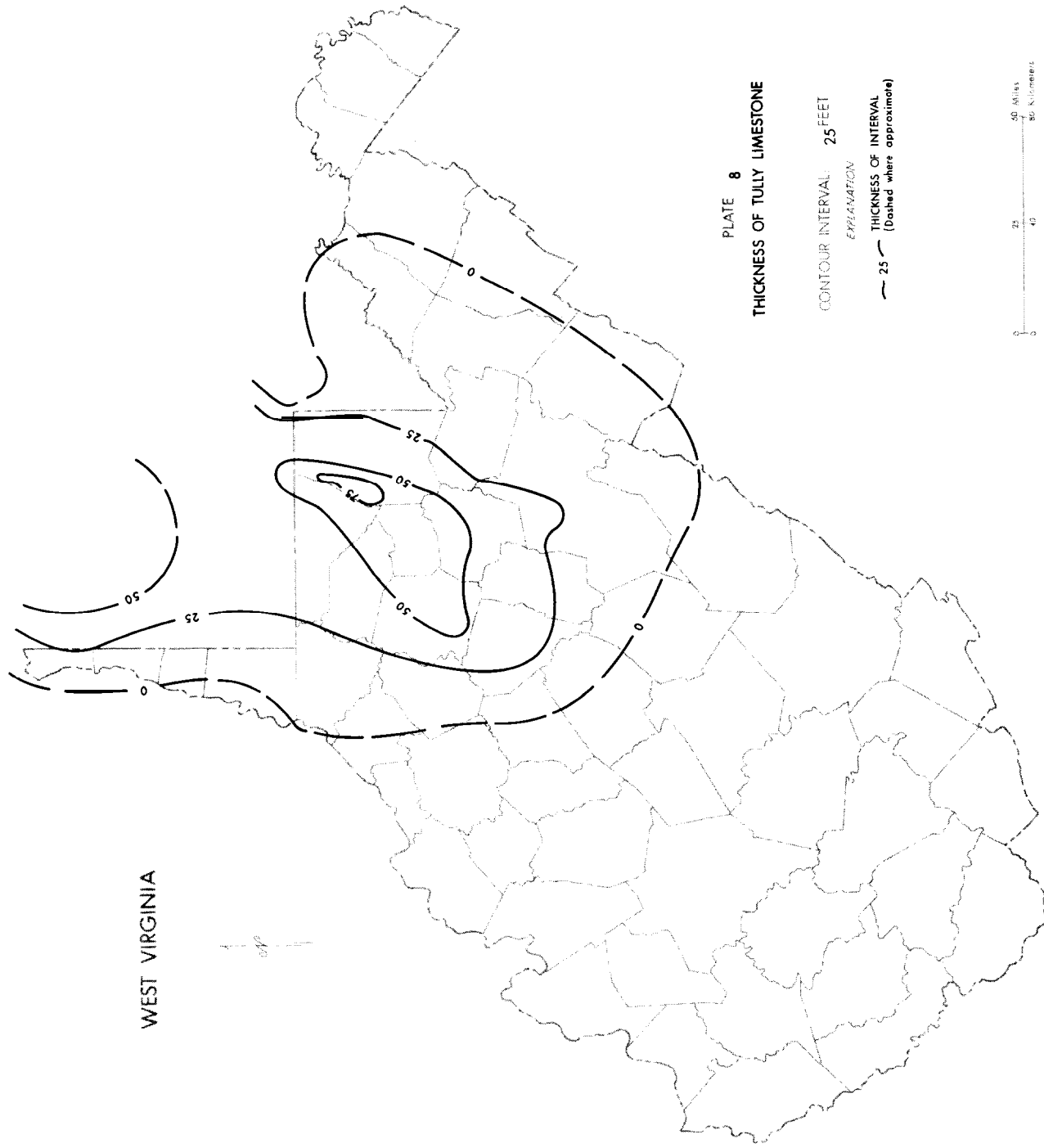


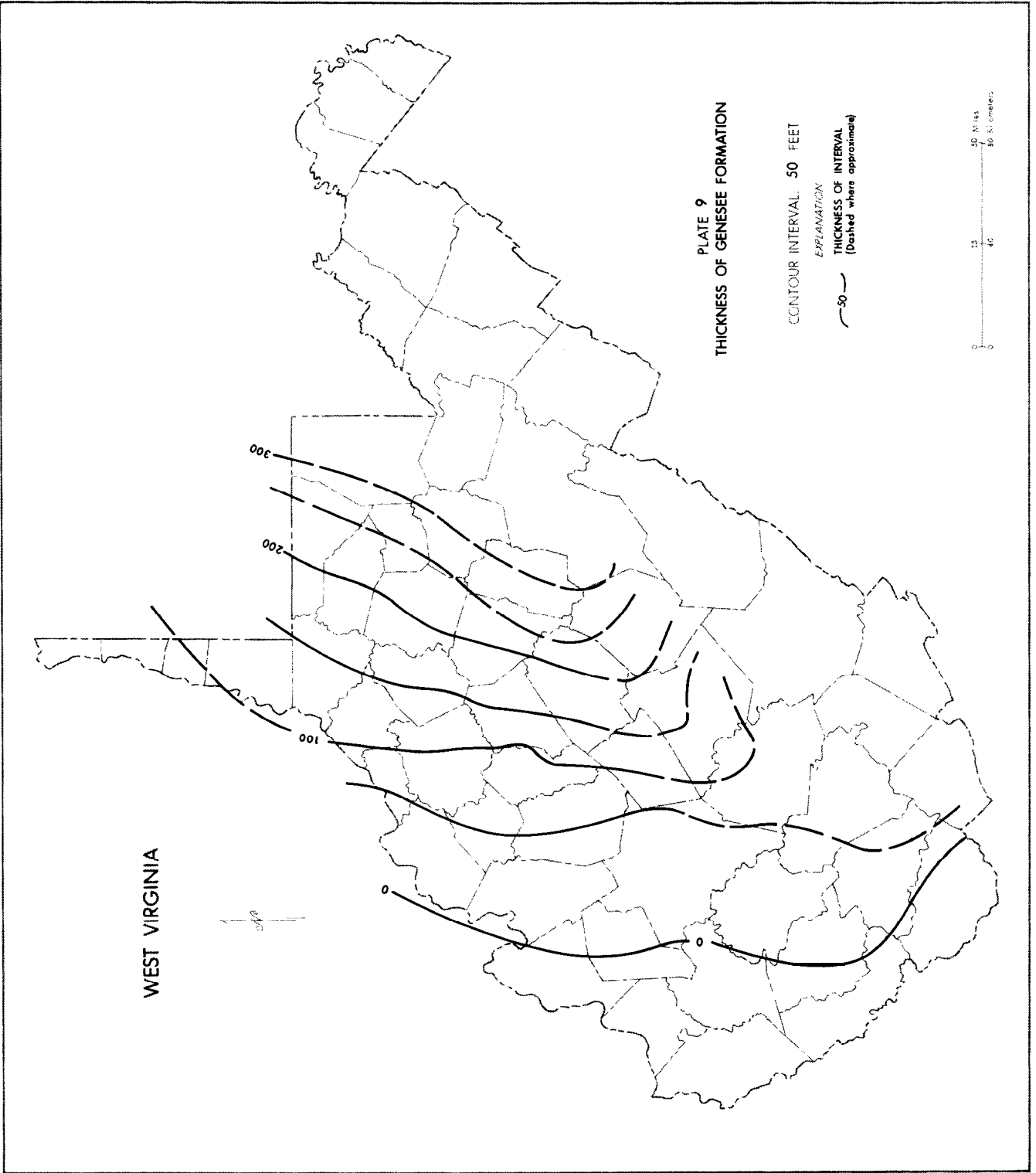
PLATE 8
THICKNESS OF TULLY LIMESTONE

CONTOUR INTERVAL 25 FEET

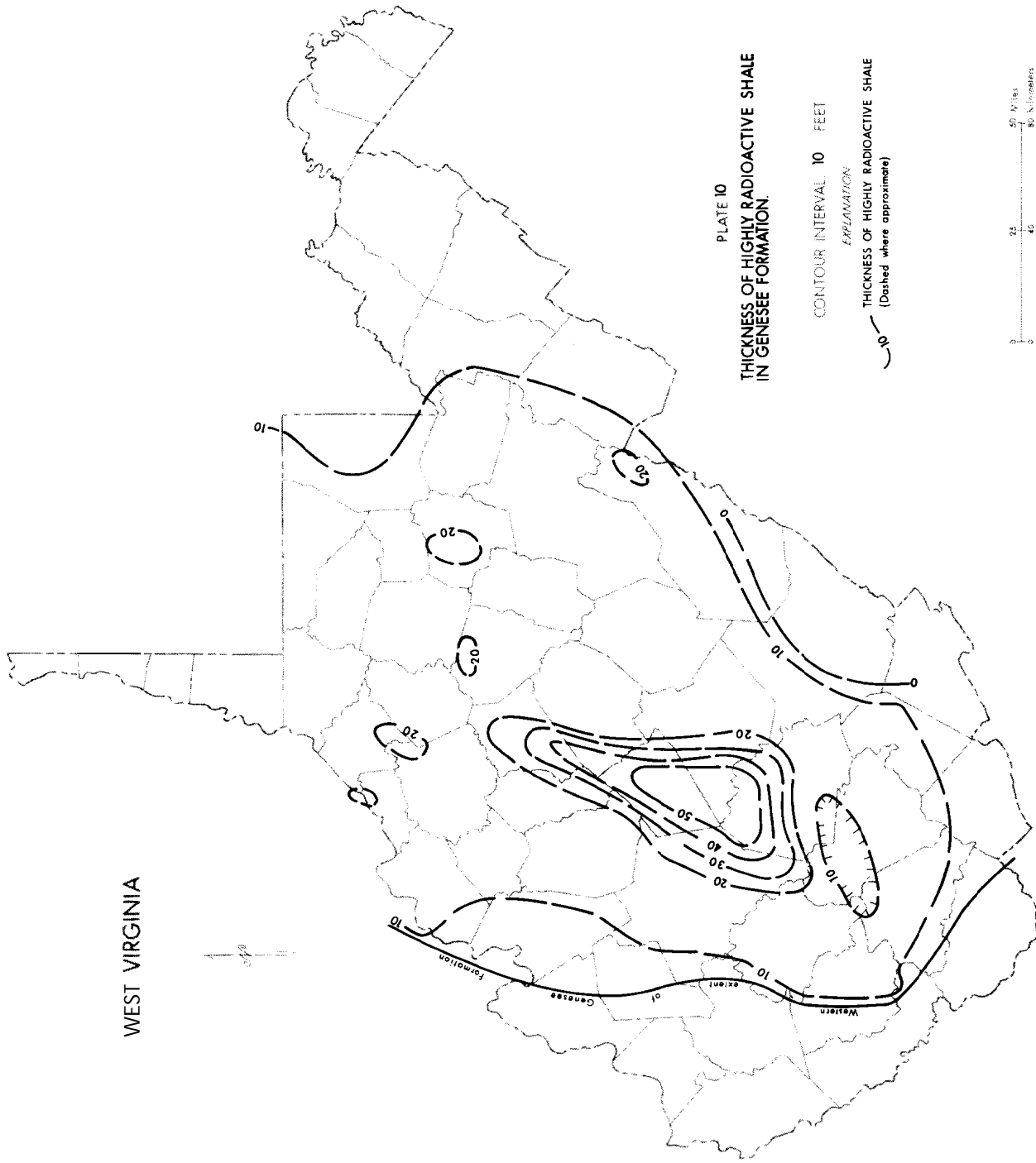
EXPLANATION

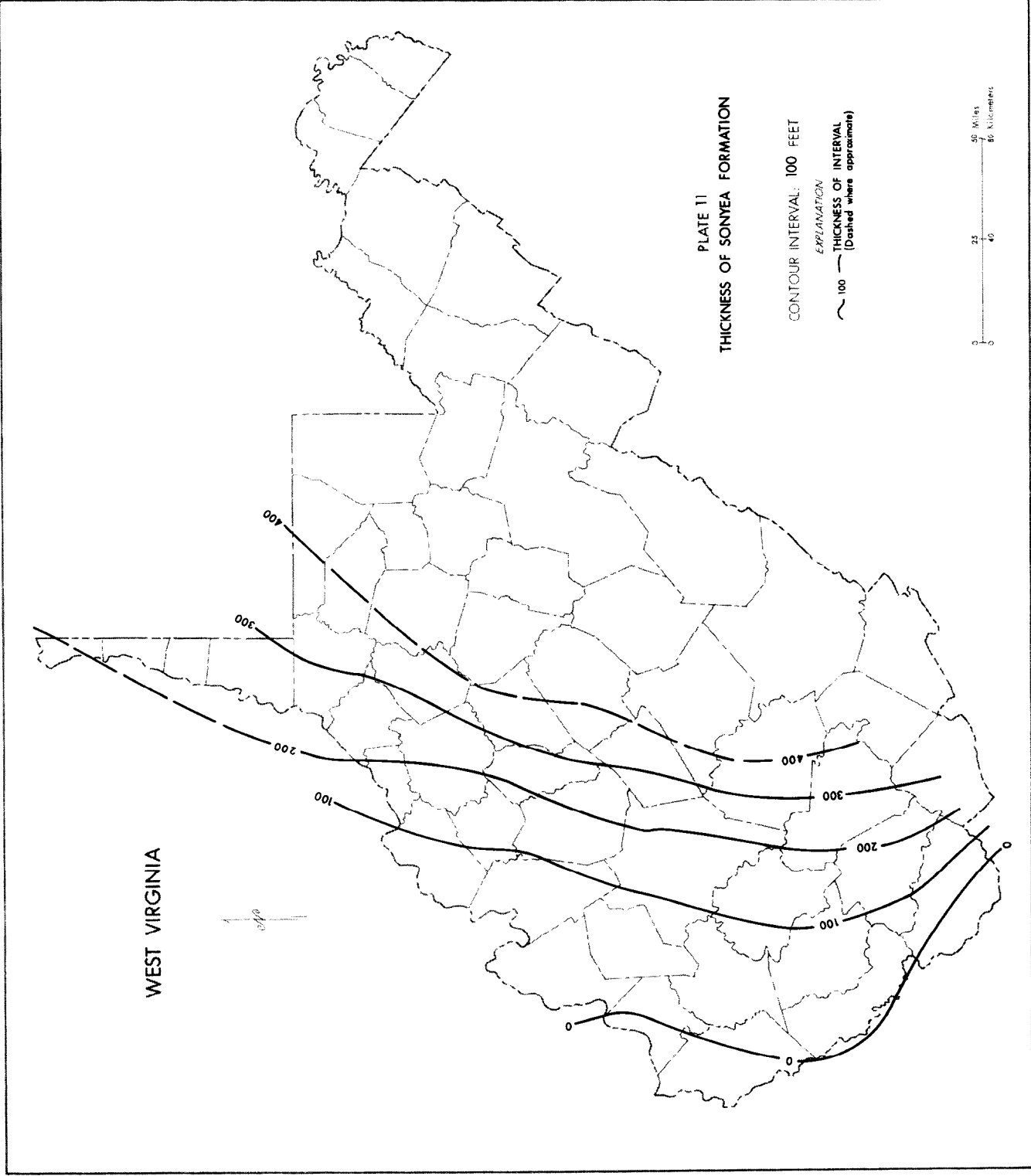
— 25 — THICKNESS OF INTERVAL
(Dashed where approximate)





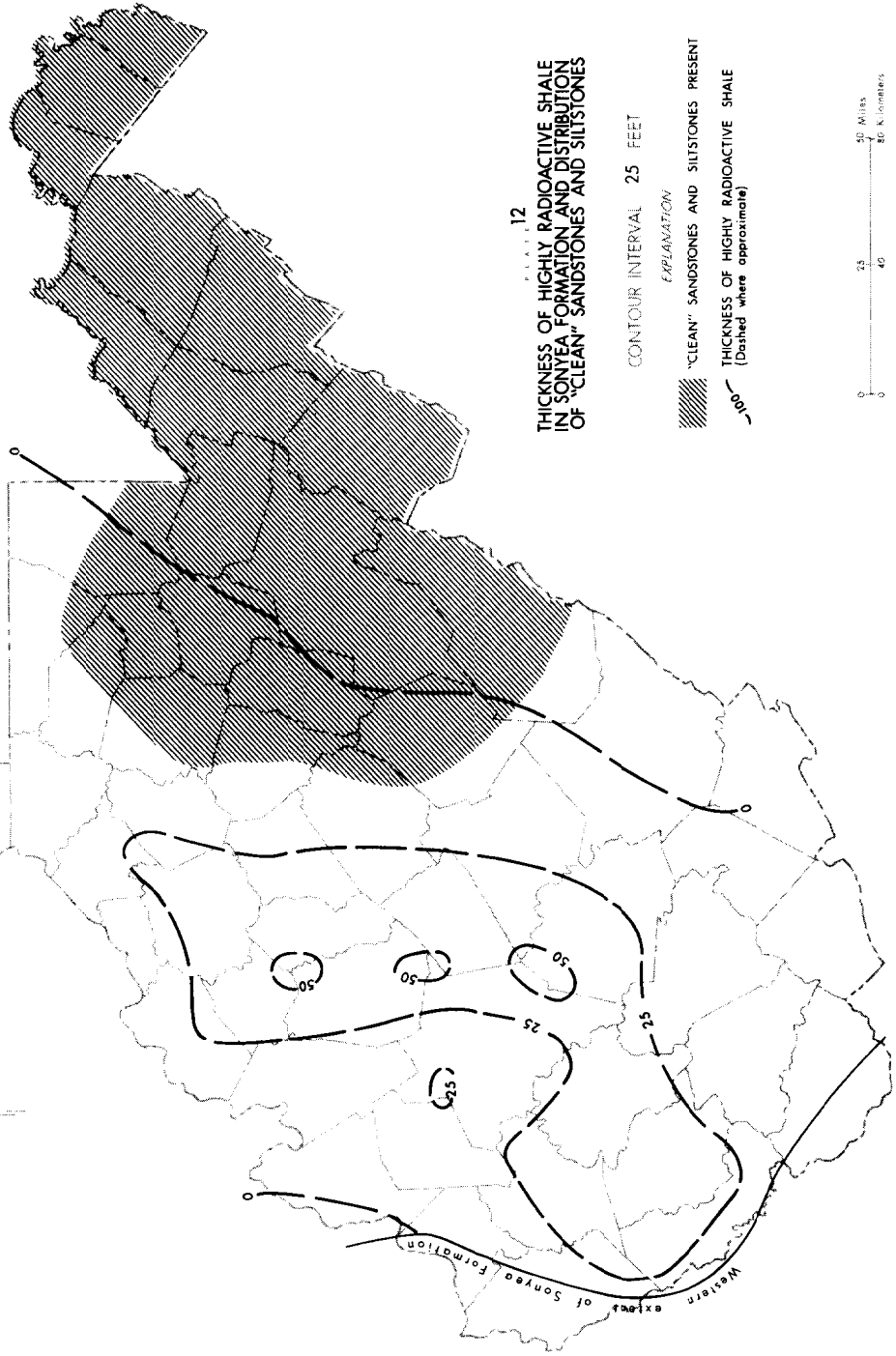
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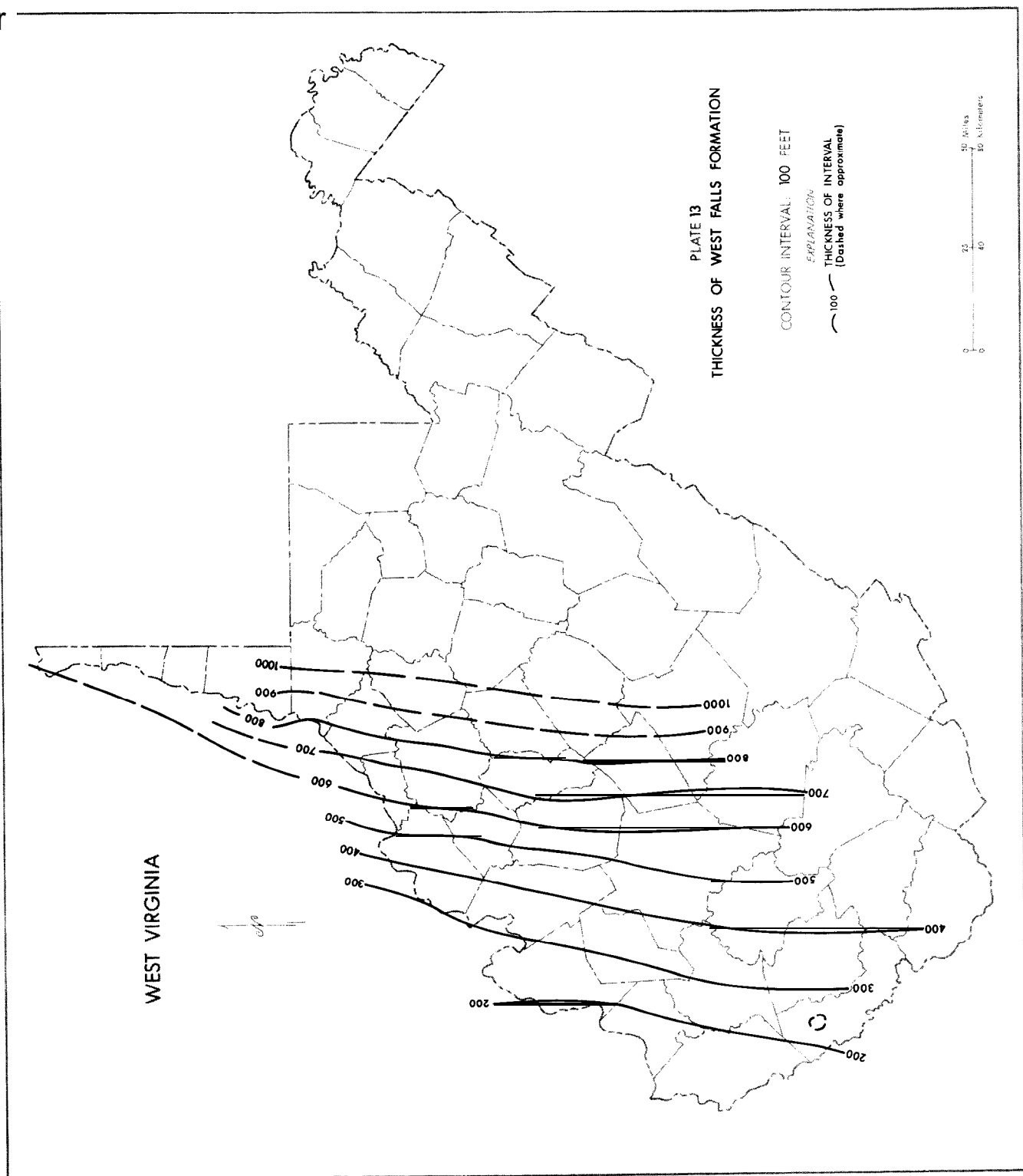




WEST VIRGINIA

0 10 20 Miles
0 16 32 Kilometers





WEST VIRGINIA

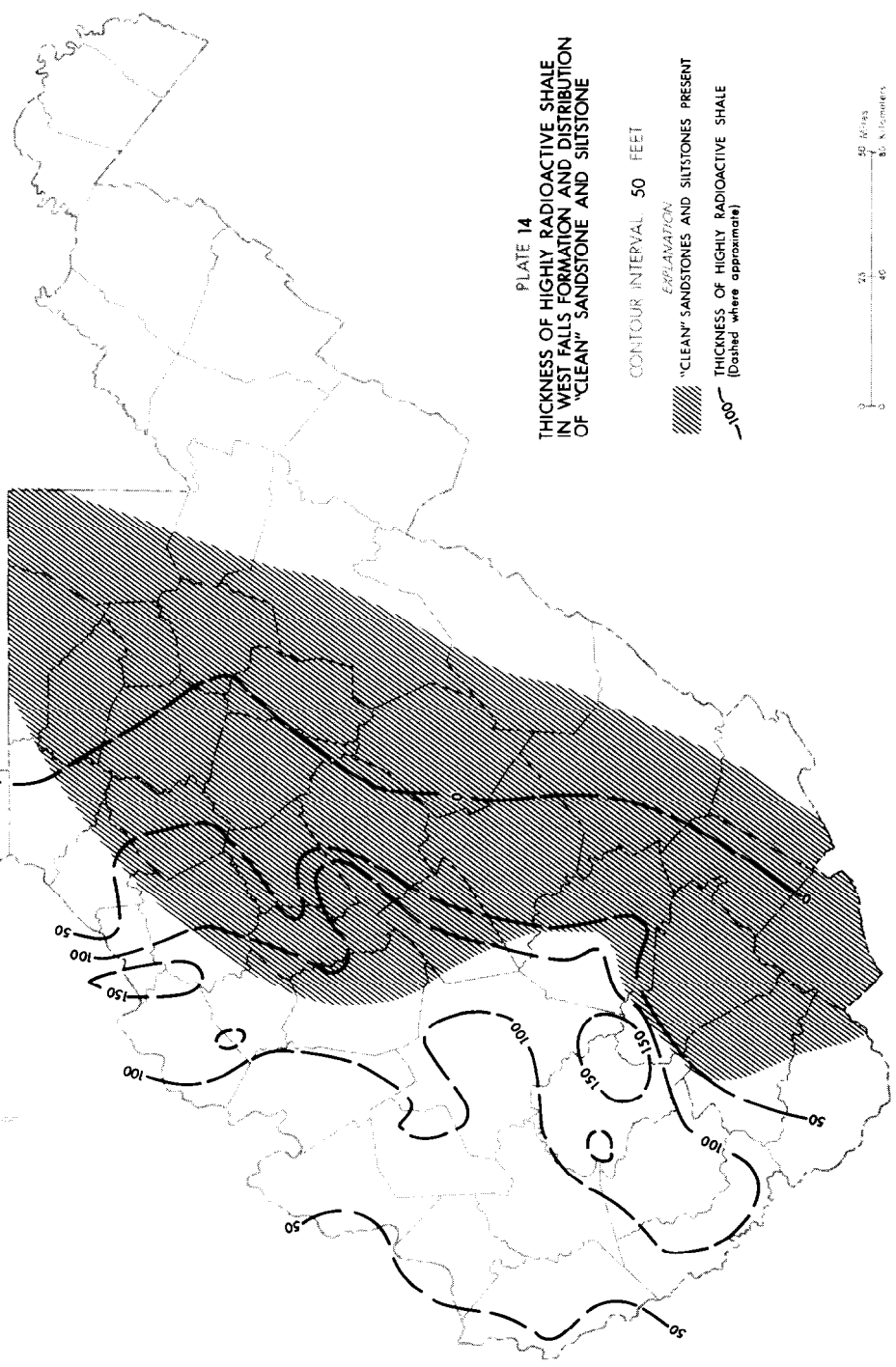


PLATE 14
THICKNESS OF HIGHLY RADIOACTIVE SHALE
IN WEST FALLS FORMATION AND DISTRIBUTION
OF "CLEAN" SANDSTONE AND SILTSTONE

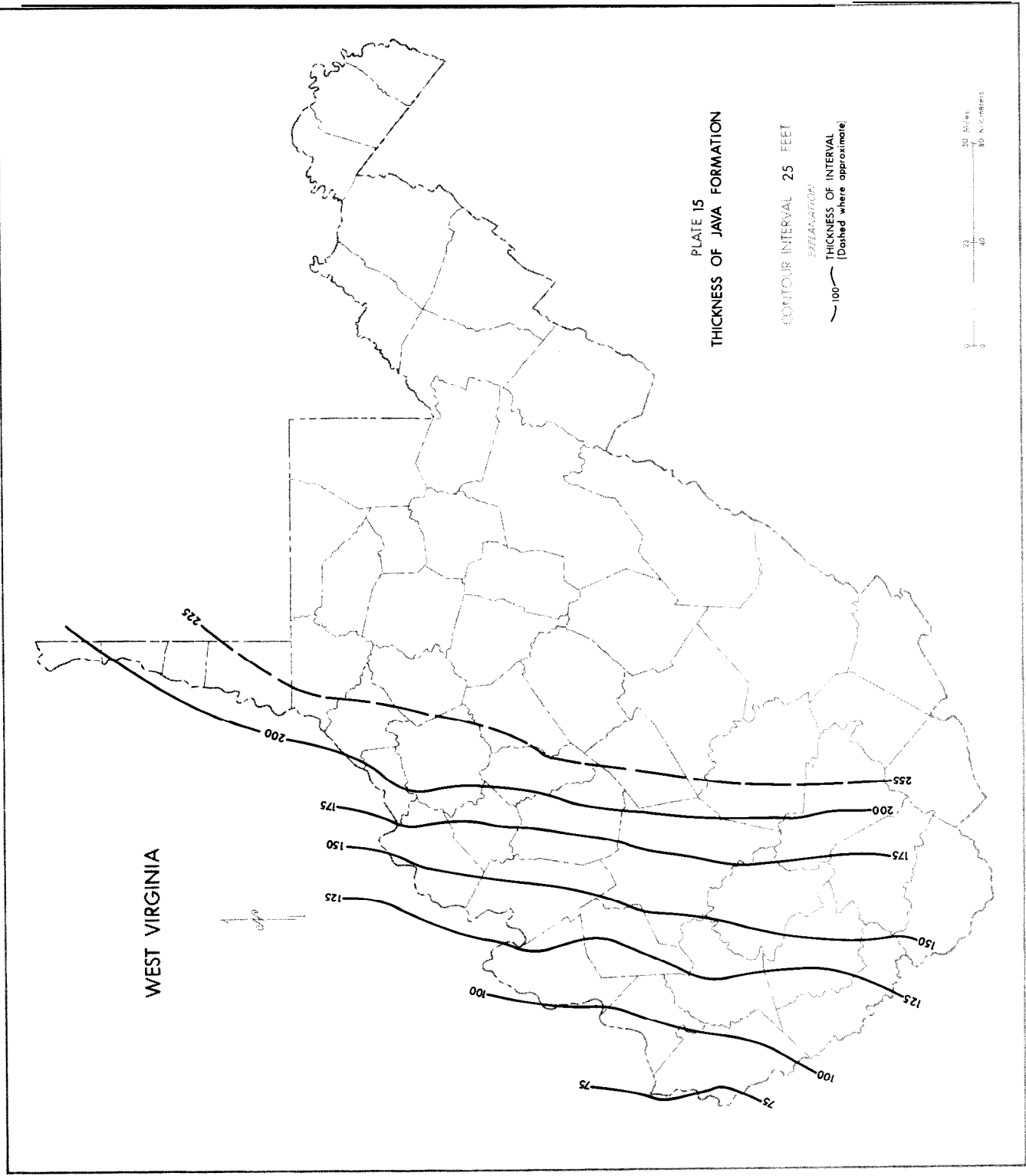
CONTOUR INTERVAL 50 FEET

EXPLANATION

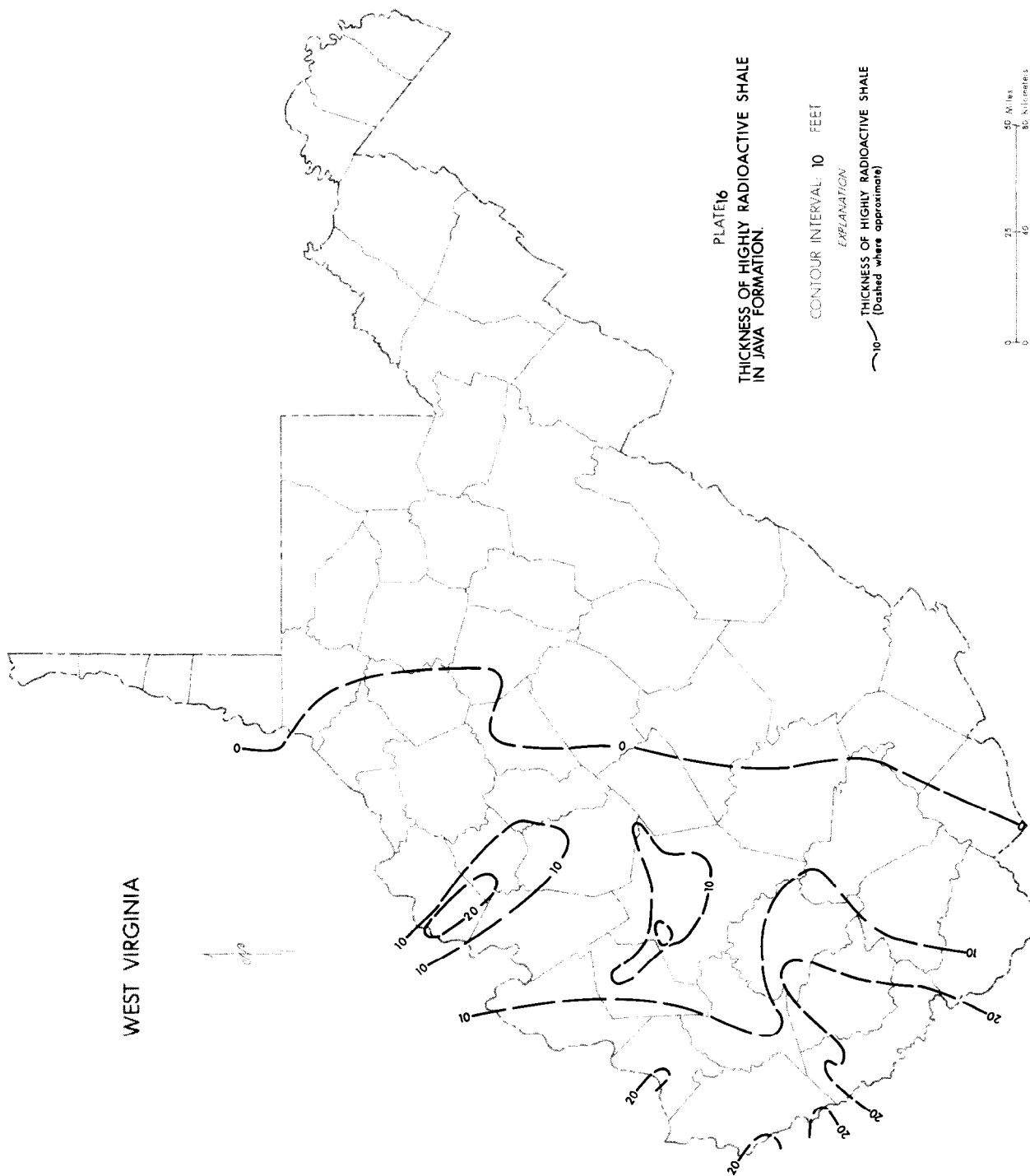
▨ "CLEAN" SANDSTONES AND SILTSTONES PRESENT

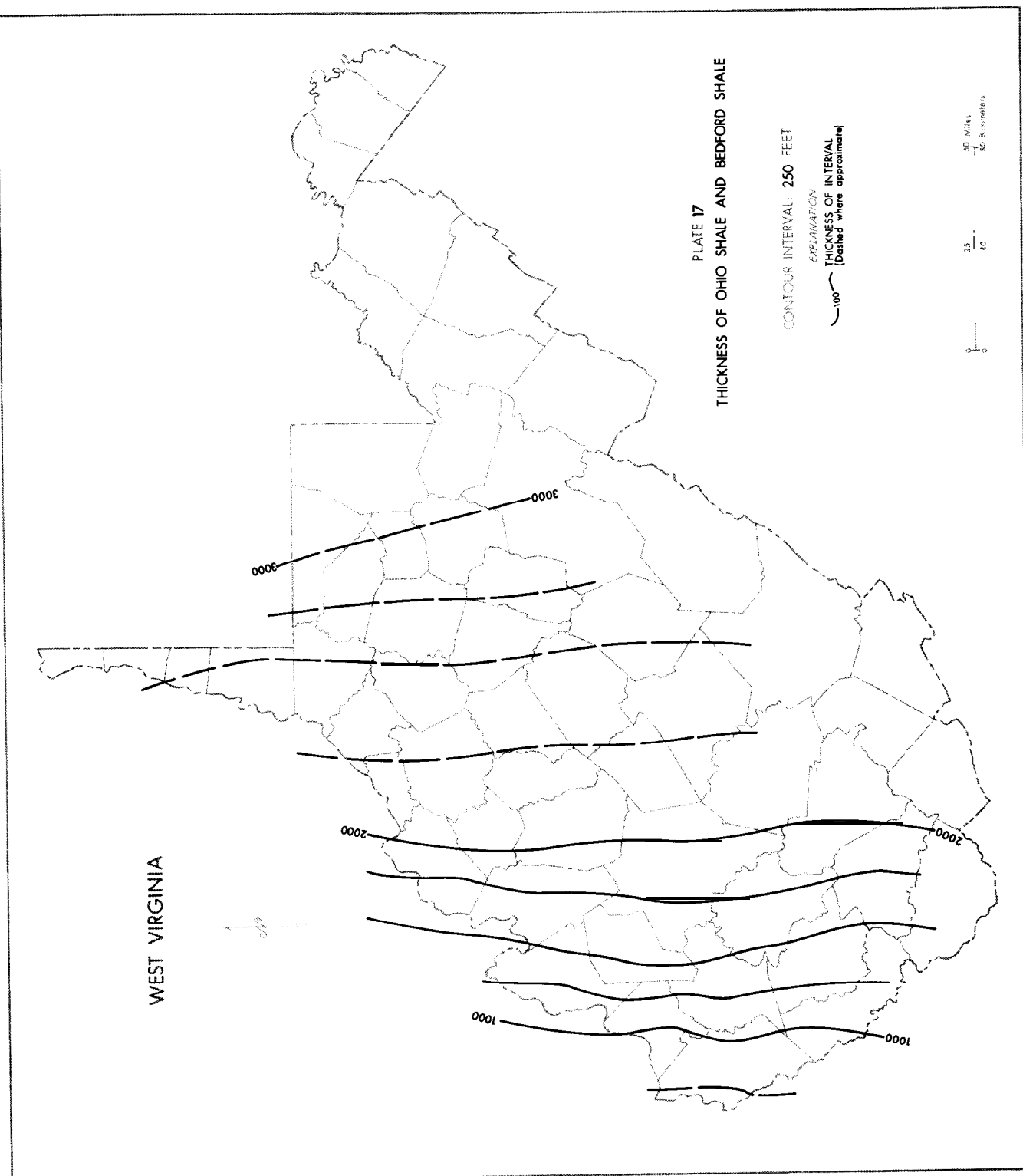
— THICKNESS OF HIGHLY RADIOACTIVE SHALE
(Dashed where approximate)





WEST VIRGINIA





WEST VIRGINIA

